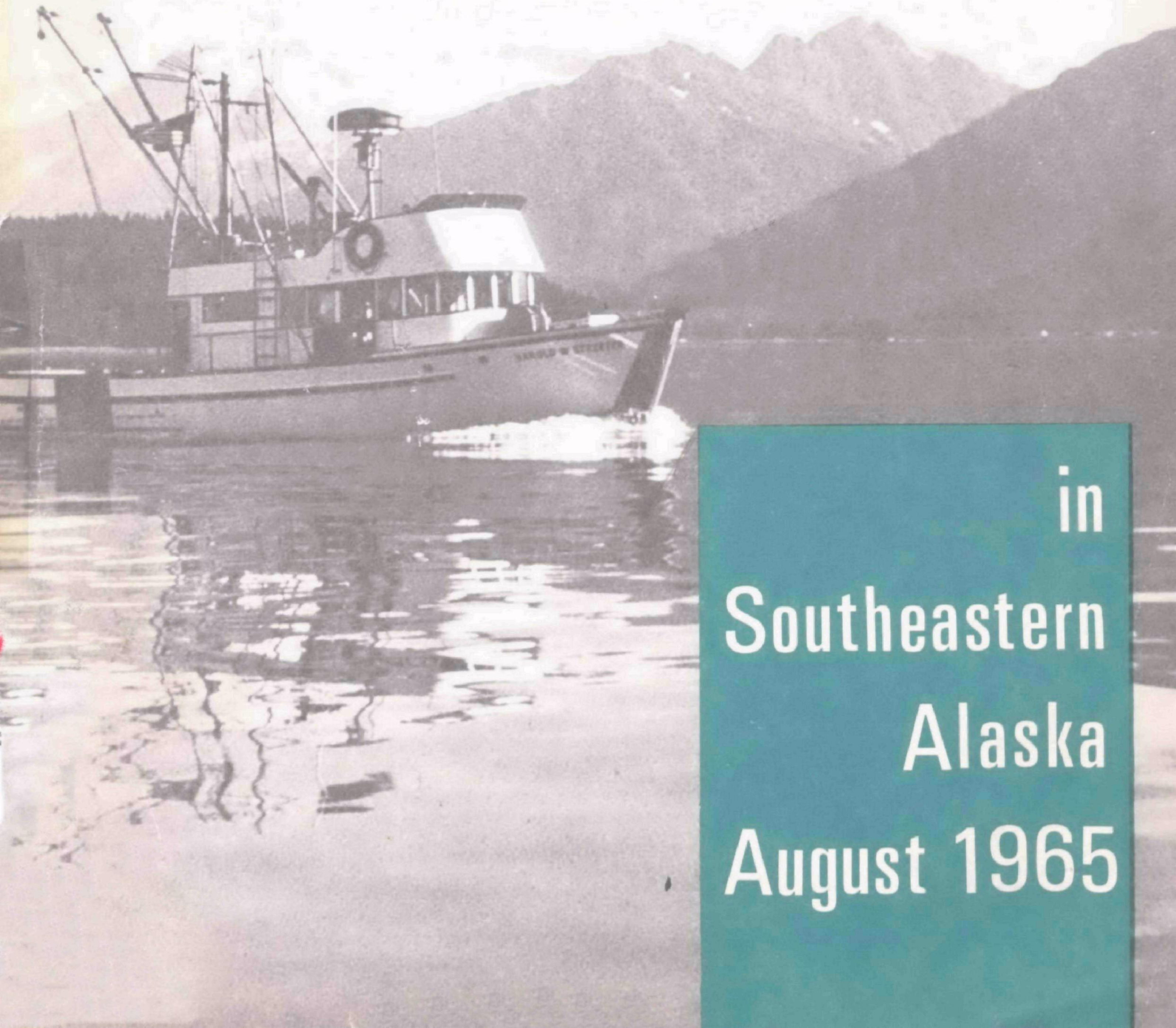
Oceanographic and Related Water Quality Studies



in Southeastern Alaska August 1965

Southeastern Alaska

OCEANOGRAPHIC AND RELATED WATER QUALITY STUDIES IN SOUTHEASTERN ALASKA, AUGUST 1965

U. S. Department of the Interior
Federal Water Pollution Control Administration
Northwest Region
Portland, Oregon

July 1966

INTRODUCTION

Upon request of the Alaska Department of Health and Welfare, related oceanographic and water quality studies were conducted at four locations in Southeastern Alaska. These studies, preliminary in nature, were conducted in: Gastineau Channel, adjacent to the cities of Juneau and Douglas; Fritz Cove-Auke Bay, near Juneau; Silver Bay, near Sitka; and Ward Cove, near Ketchikan (see Frontispiece).

The urgent need for a sewage and sewage treatment system to serve the cities of Juneau and Douglas, Alaska, and surrounding Borough necessitated the request for an oceanographic and related water quality survey of Gastineau Channel. Gastineau Channel borders Juneau, Douglas, and the expanding suburban areas, and now receives untreated and partially treated wastes from the tributary population. The Division of Health, Alaska Department of Health and Welfare, has previously recommended early development of a master sewage plan for the area, but lack of funds has precluded initiation of such a project. A preliminary study of the currents and water quality in this area was needed to provide information on the chemical and bacteriological quality of the waters in the immediate area and the Channel's ability to disperse the wastes discharged into it.

Fritz Cove is under consideration as the site for a pulp mill proposed in conjunction with plans to harvest nearly 9 billion board feet of timber from the surrounding Tongass National Forest. The Fritz Cove and adjacent Auke Bay area also is very important in its natural state because of its utilization in research programs of the U. S. Bureau of Commercial Fisheries laboratory on Auke Bay and because of its potential development as a residential and recreation area for the expanding city of Juneau. A preliminary study of Fritz Cove was needed to describe water circulation characteristics which would be pertinent to consideration of the Cove as a suitable area for discharge of pulp mill wastes.

The surveys of Silver Bay and Ward Cove were conducted to describe the distribution of wastes from pulp mill operations at these two locations and to determine the effect of these wastes on water quality. We are fortunate in this case to have comprehensive water quality information for both areas prior to commencement of pulping and discharge of wastes; studies of Silver Bay and Ward Cove were conducted by the Division of Public Health, Alaska Department of Health and Welfare prior to pulp mill construction in each area. Data from these studies were available for our evaluation of water quality changes due to pulping operations.

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CHAPTER 1

GASTINEAU CHANNEL STUDY

August 17-20, 1965

STUDY OBJECTIVES

Objectives of the Gastineau Channel Study were to:

1. Describe water circulation and water quality in Gastineau Channel with a view toward locating a proposed sewage treatment plant outfall.
2. Recommend an outfall site based on studies conducted.
3. Describe bacteriological conditions resulting from present waste disposal practices.

AREA DESCRIPTION

Gastineau Channel (Figure 1-1)* is a long, narrow tidal inlet connected to Stephens Passage at its seaward end and terminating in an extensive tide-flat area. A small navigation channel, passable only at high tide, connects the inner tide flats of Gastineau Channel with those of Fritz Cove. Depths in Gastineau Channel vary from 40 fathoms at its entrance to the exposed tide flats at its terminal end.

There are no major freshwater tributaries to Gastineau Channel. Runoff is primarily from local drainage adjacent to the channel. From surface water records (1), peak discharges occur in late summer from snowmelt and, on a mean-monthly basis, are estimated to collectively average 1,000-1,400 cu. ft. per second.

The Juneau-Douglas area of Gastineau Channel (Figure 1-2) is irregular in shape with depths varying from 20 fathoms in the expanded channel section to 11 fathoms through the channel constriction under the Juneau-Douglas Island bridge.

*Figures follow page 18

STUDIES

Investigations were focused in Gastineau Channel near the Juneau-Douglas Island highway bridge (Figure 1-2), both because of apparent increased turbulence through the channel constriction at this point, which could enhance initial waste dispersion, and because of its central location in relation to the Greater Juneau-Douglas area.

Two sampling stations, one located on either side of the bridge (Figure 1-2), were occupied over separate 12-hour tidal cycles for the purpose of describing variations in water characteristics and current, and the mixing effect of the channel constriction under the bridge. Station 1 was occupied on August 17 and Station 2 was occupied on August 18, 1965. Measurements of water temperature, salinity, dissolved oxygen (DO) content, and pH were made at hourly intervals at the surface, 2, 5, and 10 meter depths at Station 1, and the surface, 2, 5, 10, 20, and 30 meter depths at Station 2. Current speed and direction were measured at approximately half-hourly intervals at the surface and 8 meter depth at Station 1, and at the surface and 16 meter depth at Station 2.

Longitudinal distributions of salinity, temperature, dissolved oxygen, and pH at the 2 meter depth in Gastineau Channel were continuously monitored along mid-channel between Thane and Juneau boat basin (Figure 1-1) during a low water slack on August 19.

Salinity and temperature were measured at the surface, 2, 5, 10, 20, and 30 meter depths at six stations in Gastineau Channel (Figure 1-1) during a high water slack on August 20.

Current float studies were made on August 18, 19, and 20 throughout the Juneau-Douglas area of Gastineau Channel for the purpose of describing local and general water circulation patterns. Floats were released at various locations and depths during both flood and ebb tides.

Rhodamine B dye, a fluorescent tracer material, was released at the water surface under the bridge during a flood tide on August 17 and during an ebb tide on August 20. Purpose of the dye releases was to provide information on local circulation which would affect immediate waste dispersal from a source located near the bridge.

Bacteriological samples were collected on August 23 at the twenty-five stations shown on Figure 1-3. These samples, collected at low water slack, reflect the bacteriological quality of the waters adjacent to the cities of Juneau and Douglas. These waters presently are receiving raw sewage from numerous outfalls located along the waterfront (Figure 1-4).

Reduced data from all studies will be presented and discussed in this report. All raw data is on file at the Federal Water Pollution Control Administration office in Portland, Oregon.

METHODS

Water sampling and current measurements at Stations 1 and 2, and the continuous monitoring of DO, pH, and Rhodamine dye were conducted from the 45-foot oceanographic research vessel, HAROLD W. STREETER. A high-speed 14-foot outboard boat was used to conduct the current float studies, aid in the dye studies, and conduct the six-station high water slack salinity-temperature traverse along Gastineau Channel.

Individual water samples were collected using standard 1.25-liter teflon-coated Nansen bottles. A submersible pump arrangement was used to provide for continuous underway monitoring of DO, pH, and Rhodamine dye.

Salinity, in parts per thousand, and temperature, in degrees Centrigrade, were measured in situ using an Industrial Instruments, Inc. model RS-5 inductive salinometer. Occasional check measurements of salinity were made using a precision hydrometer and standard oceanographic density tables.

Dissolved oxygen content was measured using a Beckman model 777 polarographic DO analyzer calibrated in percent saturation.

pH was measured using a Beckman model Zeromatic pH meter.

Fluorescent measurements of Rhodamine dye were made with a Turner model 111 fluorometer equipped for both flow-through and discrete sample monitoring.

Current measurements at Stations 1 and 2 were obtained using two Hydro-Products Savonius-rotor current meters. Deck read-out units indicated current speed in knots and current direction in degrees magnetic. Float studies were conducted using conventional crossed-vane current drogues suspended from small marker buoys. Buoy locations were determined using a sextant and three-arm protractor.

The bacteriological samples collected were analyzed by both the membrane filter technique for total count and the most probable number coliform test as described in Standard Methods (2). The MPN determinations were conducted by the Alaska Department of Health at their laboratory, while the membrane filter analyses were conducted in the laboratory of the survey vessel HAROLD W. STREETER.

RESULTS

WATER CIRCULATION

Tides and Tidal Currents. Tides throughout the Alaska area are of the mixed semi-diurnal type characterized by two unequal high and two unequal low waters per tidal day (about 25 hours). Daily predictions of tides and currents in Gastineau Channel at Juneau are listed in the tide and current tables (3, 4) of the U. S. Coast and Geodetic Survey. Mean values listed for Juneau are as follows:

Mean Tide Range	13.8 ft.
Diurnal Tide Range	16.4 ft.
Flood Current (strength)	2 knots at 315 degrees True
Ebb Current (strength)	2 knots at 135 degrees True

Spot checks of tide height at a dockside staff gage during this study showed actual tide heights and times closely approximated those predicted. Observed times of slack and strength current agreed fairly well with those predicted, although measured velocities were erratic and slightly less than predicted values.

Currents measured at Stations 1 and 2 are shown on Figures 1-5B and 1-6B, respectively. Velocities are shown full value as observed in either flood (northwesterly or up-channel) or ebb (southeasterly or down-channel) direction without regard to specific direction measured. Current direction at Station 1 was generally oriented up- or down-channel without much cross-channel tendency. Current direction at Station 2 had an intermittent set toward Douglas Island, apparently due to eddy action in the expanded channel section of Juneau harbor. Surface currents at both stations were stronger than those measured at depth.

Strength of flood and strength of ebb near-surface current patterns are shown on Figures 1-7 and 1-8, respectively, as composited from current measurements and the several float studies made in the area. Floats released under the bridge on a flood tide consistently moved toward the Juneau shore, occasionally entering the boat basin through its northwest entrance. Floats released under the bridge during either flood or ebb tide did not move completely out of the Juneau-Douglas study area (Figure 1-2) during a single tidal excursion.

A flood tide release of Rhodamine dye under the bridge near the Douglas Island side moved quickly cross-channel and flooded up along the Juneau shore. Much of the dye moved into the boat basin through its northwest entrance, with the remainder eventually moving around the entrance jetty and up-channel along the Juneau shore. Dye released as a continuous line between the bridge piers on an ebb tide moved mainly down-channel as expected but with some up-channel movement by eddies near each shore. The main portion of the dye disappeared into several tide tips as it reached the expanded channel section. Fluorometric monitoring of this dye release after low water slack showed considerable quantities of dye along the Juneau shore in the expanded channel section. Sketches of successive dye positions are shown on Figures 1-9 and 1-10 for both the flood and ebb dye releases, respectively.

Salinity-Freshwater Relationships. Salinity measurements with depth showed considerable depression of near-surface salinities, apparently from widespread melting of snow and glaciers throughout the Stephens Passage area, rather than from local sources in Gastineau Channel. Annual cycles of salinity, temperature, and dissolved oxygen distributions with depth are shown in Figure 1-11 for a station in outer Auke Bay (Figure 1-1), based on data provided by U. S. Bureau of Commercial Fisheries, Auke Bay Laboratory. The figure indicates that conditions of extensive surface layering of fresh water prevails from June through September.

Observed longitudinal salinity distribution in Gastineau Channel near high water slack on August 20 is shown on Figure 1-12. Salinities, temperatures, and the resultant densities (in terms of specific gravity) for Station 1 on August 17 and Station 2 on August 18 are shown on Figures 1-5C, D, and E, and 1-6C, D, and E, respectively. Some features noticed in comparison of these graphs are:

a. Layering of fresher water near the surface is generally prominent to depths of 5-10 meters.

b. A definite tendency of surface salinity to increase toward the upper end of Gastineau Channel (Figure 1-12) indicates that the major source of the observed fresh water is from Stephens Passage, rather than from up-channel sources.

c. Higher surface salinities on the ebb than on the flood at Station 2, and a corresponding reduction in density stratification (Figure 1-6C and E), indicate mixing of the water column in the area up-channel from Station 2. This is probably due both to local mixing through the channel constriction under the bridge area and to general mixing in the tide flat areas of upper Gastineau Channel. Since a similar trend is not as prominent at Station 1 (Figure 1-5C and E), it appears that a significant portion of the mixing occurring up-channel from Station 2 occurs in the area between Stations 1 and 2.

One of the effects of increased surface salinity in the bridge area is to produce tide-rips whenever a mass of heavier water (more saline) meets with a mass of lighter water (less saline). The heavier water sinks under the mass of lighter water to produce tide rips at the interface. Several tide-rips were noticed in Gastineau Channel, particularly immediately above the bridge during the first part of the flood tide and below the bridge during the first part of the ebb tide. Current floats would not cross a tide-rip but would travel rapidly along it, resulting in a congregation of floats at the end of the rip. Surface dye was observed to sink at the rip as previously noted.

Net Circulation. In a long, narrow tidal channel, such as Gastineau, closed at one end and open to the sea and tides at the other, there is generally no net transport provided by the tidal currents. Water leaving the channel on the ebb tide equals that entering on the flood tide, with no net predominance either into or out of the channel. However, freshwater entering the channel from local sources (rivers, creeks, glacier melt, rain, etc.) lies near the surface and must eventually move to sea, producing a net outflow near the surface of the tidal channel. Saline water from depth which mixes with this freshwater, and is eventually carried outward with it, must be replaced by a net inward motion at depth. The extent to which this two-layer system develops and the rate at which the net motion proceeds depends on channel geometry, tides, and freshwater discharge. Review of surface water data published by U. S. Geological Survey (1) shows that local runoff to upper Gastineau Channel is minor when compared to the tidal flow, thus indicating that net seaward motion due to freshwater inflow is also minor.

Based on the salinity observations previously discussed, it is evident that a significant freshwater layer was present in Gastineau Channel during the time of measurement. The major freshwater source, however, was from the seaward end of the channel, rather than from within the channel. Sinking of the heavier water mass created by mixing above Station 2, and subsequent inward spreading of the fresher layer over it, provides a mechanism whereby net motion in Gastineau Channel may actually be inward at the surface and outward at depth. Current readings at Station 2 (Figure 1-6B) were too erratic to reliably describe such a motion, but those at Station 1 do exhibit a tendency for flood direction predominance at the surface and ebb direction predominance at depth. However, since the channel becomes quite shallow immediately above Station 1, this point would be near the upper limit of such a net circulation.

One other factor which could affect net circulation in Gastineau Channel is the possibility of a significant tidal exchange through the tide flat area between upper Gastineau Channel and Fritz Cove. Examination of current meter data collected in the small navigation channel through this area in 1963 by U. S. Geological Survey (5) indicates that a nodal point of no-net-flow does occur, thus minimizing the probability that flow to or from Fritz Cove (and Mendenhall River) is a significant factor in Gastineau Channel circulation.

WATER QUALITY

Dissolved Oxygen. Dissolved oxygen content in natural waters may be increased through surface reaeration and phytoplankton productivity (during sunlight) and decreased by organic demands and plankton respiration (during darkness). Since the only mechanism for increasing dissolved oxygen occurs at or near the surface, dissolved oxygen normally decreases with depth, particularly in a stably stratified water mass where vertical mixing is slow. Near-surface coastal waters are often super-saturated with DO in the spring and summer due to plankton productivity stimulated by nutrients, sunlight, and elevated water temperature. DO values usually drop during the fall and winter when nutrient supply decreases (from productivity), sunlight and water temperature decrease, and some oxygen demand is exerted by oxidation of the dead plankton population. Another significant factor affecting the dissolved oxygen content of Pacific coastal waters is the upwelling which occurs along the outer coast during spring and summer due to coastal winds. Surface waters transported offshore are replaced nearshore by high salinity, low oxygenated water from depth. By virtue of its higher density, this upwelled water slowly spreads at depth into the coastal bays, sounds, inlets, etc., and is initially manifested in the inner reaches by late summer or early fall as high salinity and low oxygen concentration near the bottom. Slow mixing thereafter results in generally depressed oxygen conditions throughout the water column during late fall and winter. The essential features of such a typical annual DO cycle are noticeable at the Auke Bay station as illustrated on Figure 1-11C.

Dissolved oxygen concentration at the two-meter depth in Gastineau Channel, monitored between Thane and Juneau boat basin (see Figure 1-1) near low water slack on August 19, varied between 100% and 112% saturation with most of the readings at 104-106%. No particular trend was observed as far as longitudinal distribution was concerned. DO was generally at or above saturation at depths less than 5 meters.

DO concentrations observed over the tide cycle at Stations 1 and 2 are shown on Figures 1-13B and C and 1-14B and C, respectively. One notable feature of these distributions is increased DO concentration at depth during ebb current, an indication of mixing up-channel from both stations.

pH. pH of Pacific coastal waters varies between about 7.5-8.5 depending on depth, time of year, etc. Seawater is considerably buffered against pH changes but can be altered by both dilution from freshwater inflow and by addition or depletion of CO_2 through atmospheric interchange or biologic activity. An addition of CO_2, such as during plankton respiration, decreases the pH of seawater; while depletion of CO_2, such as during plankton productivity, increases the pH.

pH values observed over the tidal cycle at Stations 1 and 2 are shown on Figures 1-13D and 1-14D, respectively.

Bacterial Quality. Raw sewage is presently discharged into Gastineau Channel from numerous outfalls located principally in the immediate waterfront areas of the cities of Juneau and Douglas (Figure 1-4). The presence of this raw sewage in the immediate waterfront areas represents a potential health hazard to those working on, and who have contact with, the water.

On August 23, some 25 samples were collected at low tide from stations in Gastineau Channel and analyzed for the presence of those bacteria associated with human wastes. Stations sampled are indicated on Figure 1-3. Results of these analyses, which are tabulated below, indicate that MPN's in excess of 1,000/100 ml occur at most stations located in the active waterfront areas. The Division of Public Health of the State of Alaska, Department of Health and Welfare, recommends that MPN not exceed 1,000/100 ML for waters used for boating, fishing, and related commercial activities.

BACTERIOLOGICAL RESULTS
August 23, 1965

Sampling Station	MPN's per 100 ml
1	240
2	240
3	240
4	240+
5	240
6	240+
7	380
8	240+
9	2,400+
10	2,400
11	2,400+
12	2,400+
13	150
14	88
15	2,400
16	2,400
17	15
18	2
19	240+
20	38
21	2,400+
22	2,400
23	960
24	240+
25	150

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The salinity-freshwater relationships prevailing during the study period were not representative of winter conditions. However, there are several pertinent factors which have been described:

1. Significant mixing occurs between Stations 1 and 2, which would enhance initial waste dispersion from a source in this area.
2. Flood current past the restricted portion of the channel near the bridge favors the Juneau shoreline, resulting in considerable circulation of main channel water through the boat basin.
3. Local eddies are formed near both the Juneau and Douglas Island shorelines adjacent to the bridge, and during ebb current in the main channel carry water up-channel along both shores.
4. Large eddies exist in the expanded section down-channel from the bridge during both flood and ebb current.
5. Net transport out of the channel is very slow with a slight tendency for inward surface motion to the bridge area during the summer.

Some general statements may be made concerning Gastineau Channel circulation in the absence of fresher surface waters from Stephens Passage, descriptive of winter conditions:

1. Local flood and ebb current patterns and eddies would remain basically unchanged except for tide-rip activity which should diminish.

2. Mixing near the bridge would increase slightly, due to lessening of density stratification.

3. Net circulation would continue to be very slow but with some slight near-surface movement seaward due to local freshwater inflow.

RECOMMENDATIONS

Outfall Location. In order to best take advantage of the above factors in minimizing the effects of waste effluents on the waters of Gastineau Channel, the following recommendations are made:

1. Locate the outfall down-channel from the bridge about midway between the bridge and the expanded channel section. Preference should be given to the Juneau shore, but consideration of a Douglas Island site may be given subject to 2. below.

2. The terminal end of the outfall should extend at least 100 feet beyond the nearshore eddy limits to minimize local concentration of effluent along the shore. Based on the studies, estimated location of the terminal end would be at the 40 foot depth contour (referenced to mean lower low water). This submergence would contribute significantly toward initial waste dispersal due to mixing of the buoyant waste plume as it rises.

The above recommendations envision at least a primary treated effluent with chlorination. Any compromise selection of the outfall site due to construction costs, right of way, etc., should include consideration of a higher degree of treatment, or be based on further study of the area.

Follow-up Studies. Before final site selection and outfall and treatment plant design are made, the following investigations should be undertaken:

1. Determine the exact limits of any nearshore eddy at the outfall site selected. This should be done for both flood and ebb current and could be accomplished using either floats or dye.
2. Determine the path of flood and ebb tidal excursion from the selected outfall site. This could be accomplished by releasing floats or dye over the outfall site at slack current and monitoring subsequent water movement until the following slack.

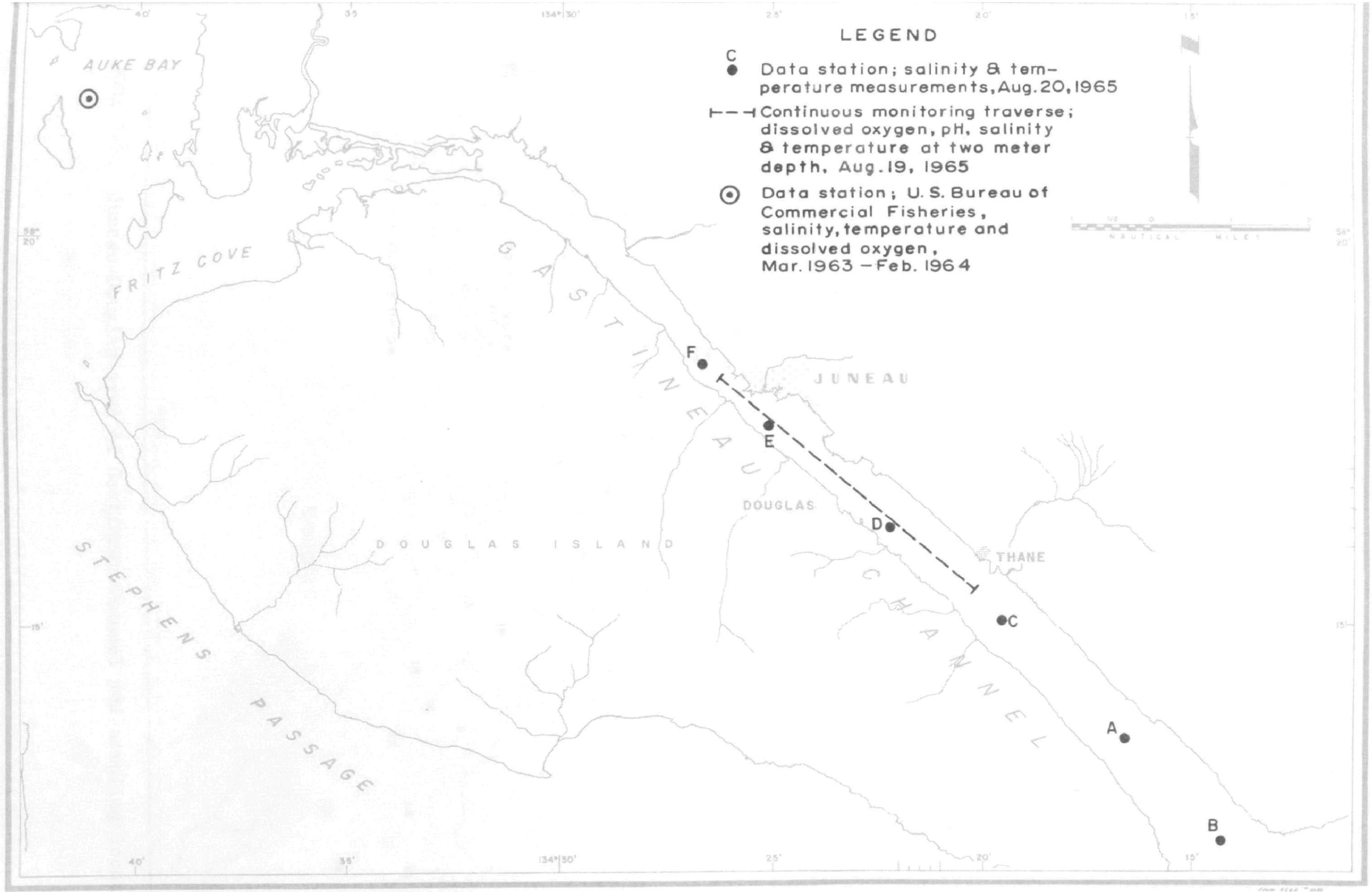

FIGURE 1-1. Gastineau Channel area and sampling locations.

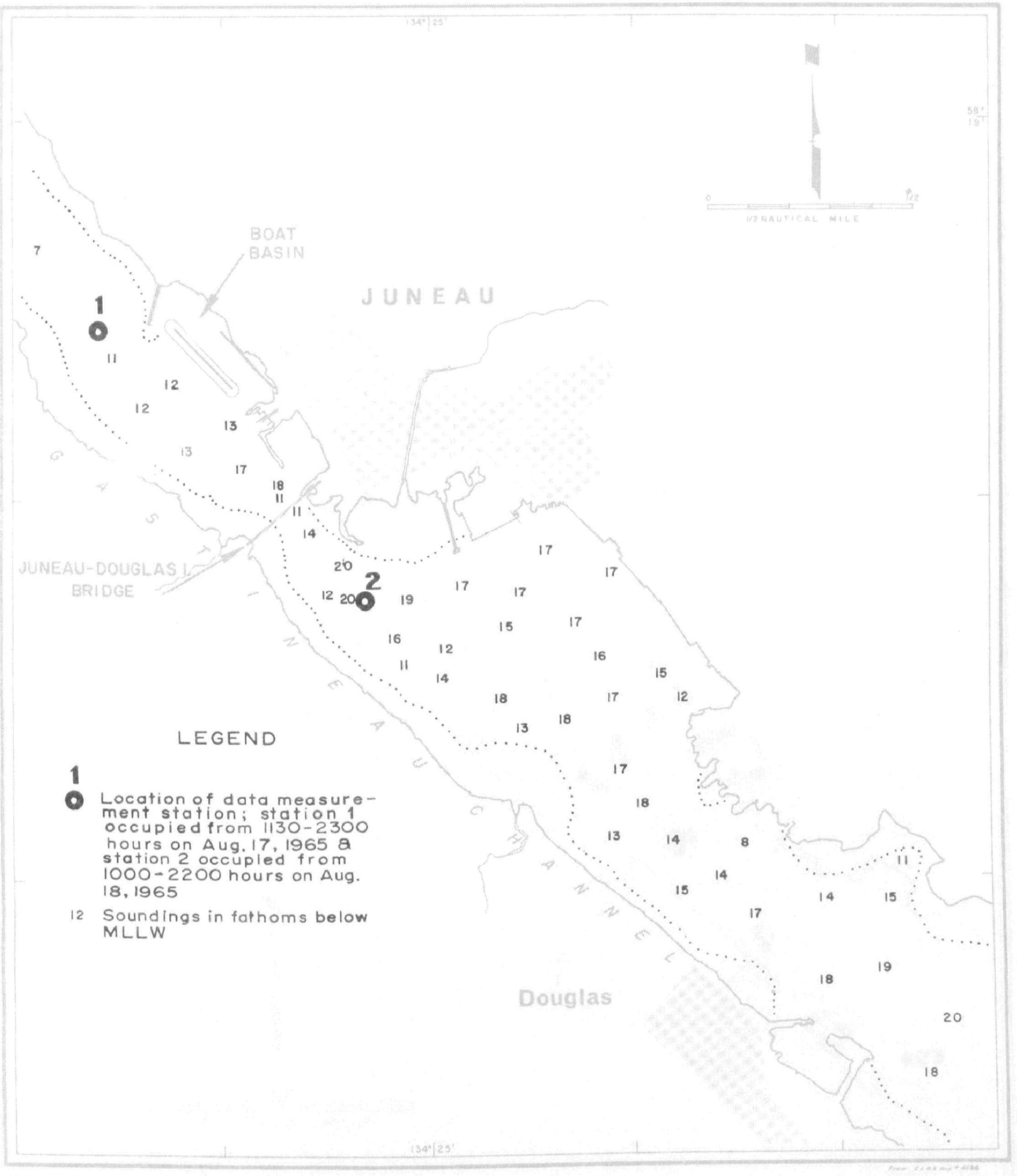

FIGURE 1-2. Juneau-Douglas area of Gastineau Channel and sampling locations.

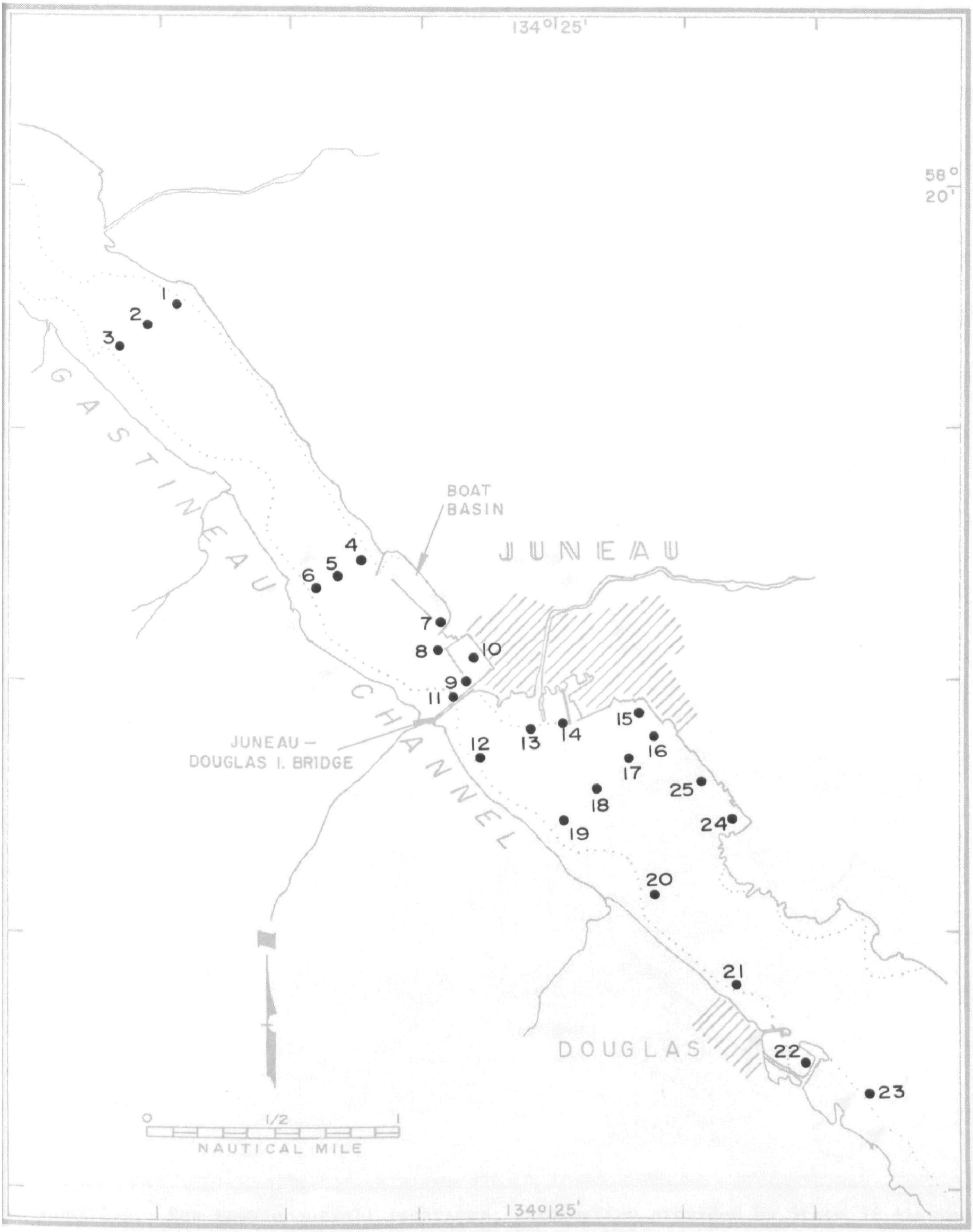

FIGURE 1-3. Bacteriological sampling locations - August 23, 1965.

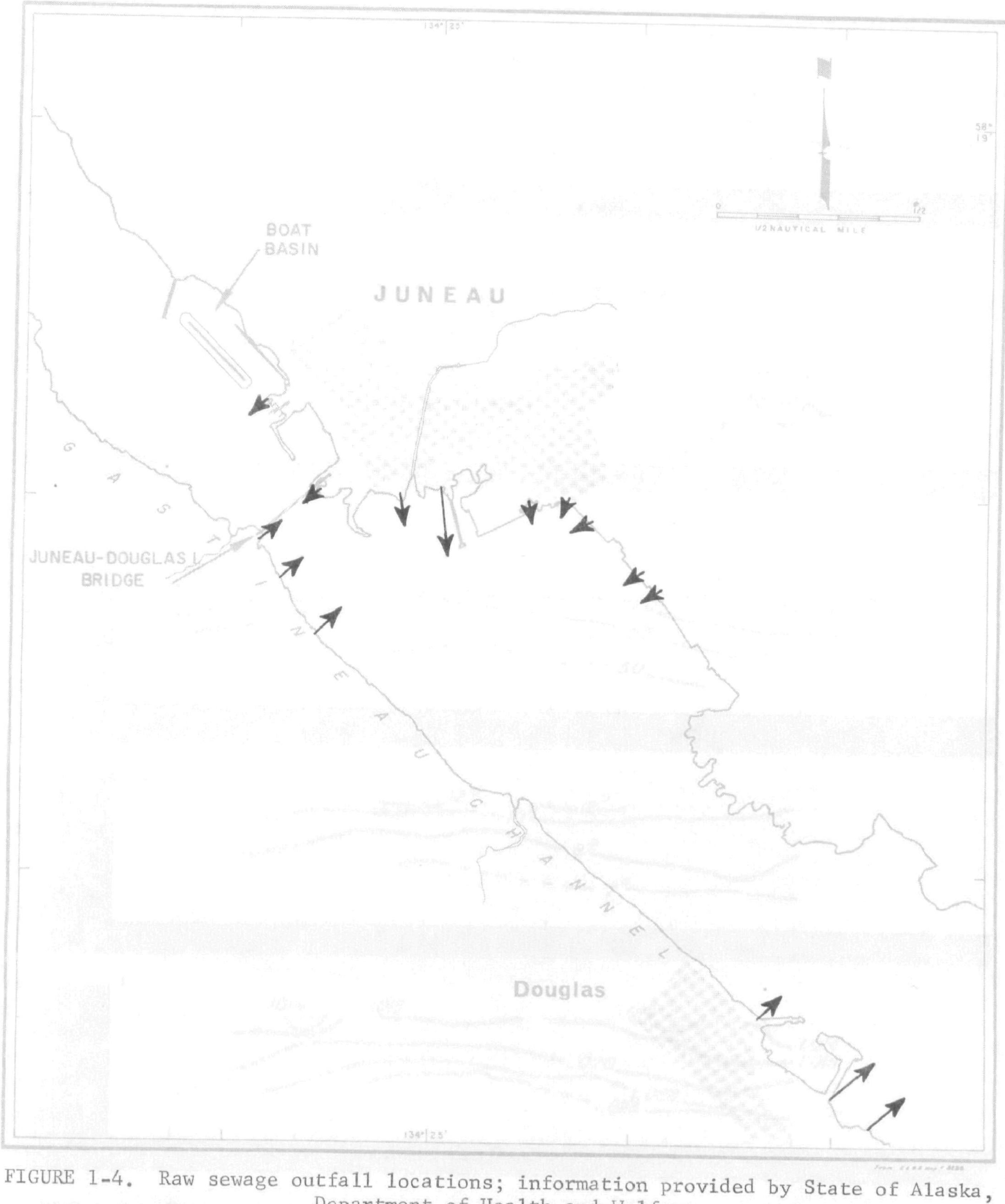

FIGURE 1-4. Raw sewage outfall locations; information provided by State of Alaska, Department of Health and Welfare.

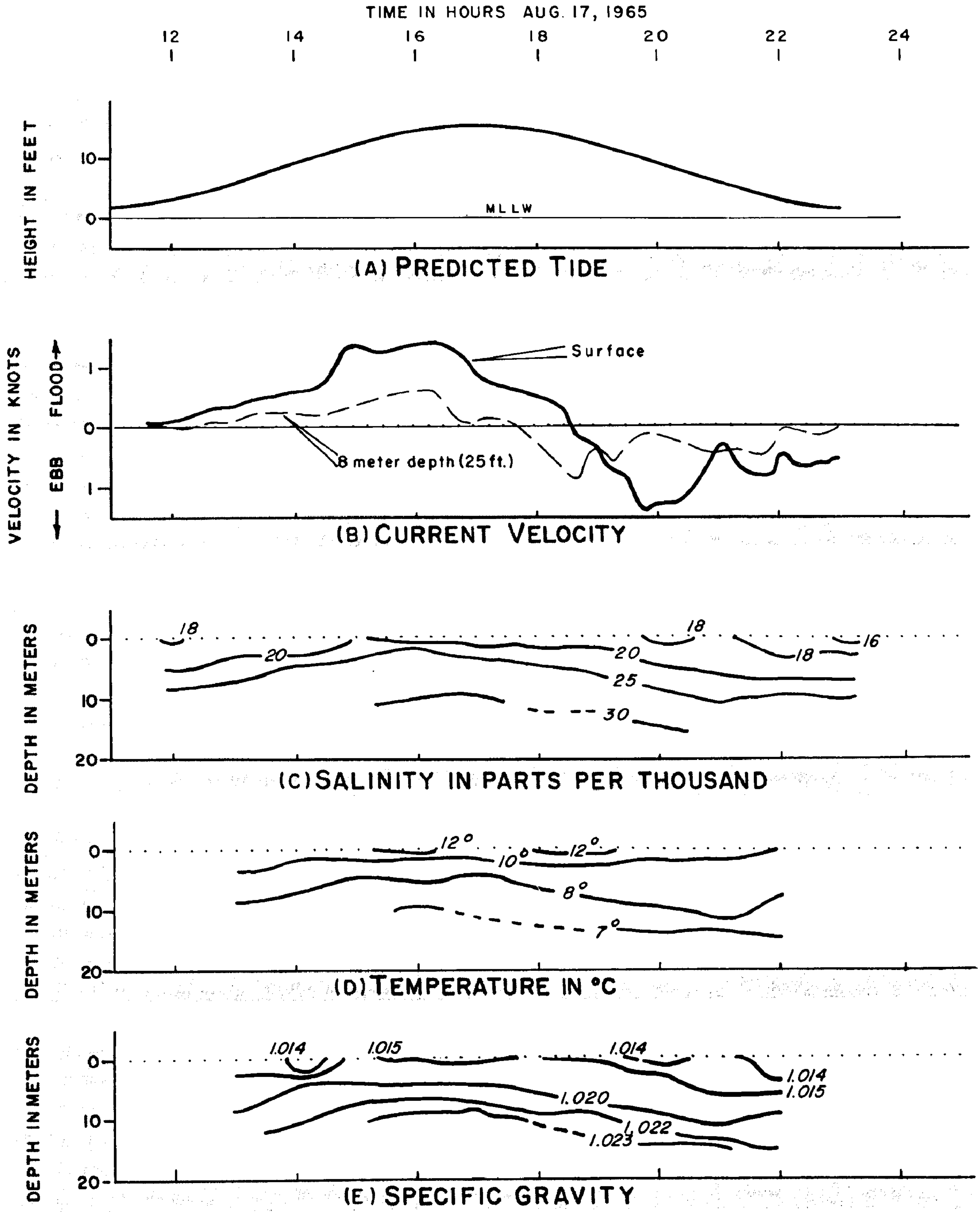

FIGURE 1-5. Patterns of (B) current velocity, (C) salinity, (D) temperature and (E) specific gravity observed at Station 1 on August 17, 1965.

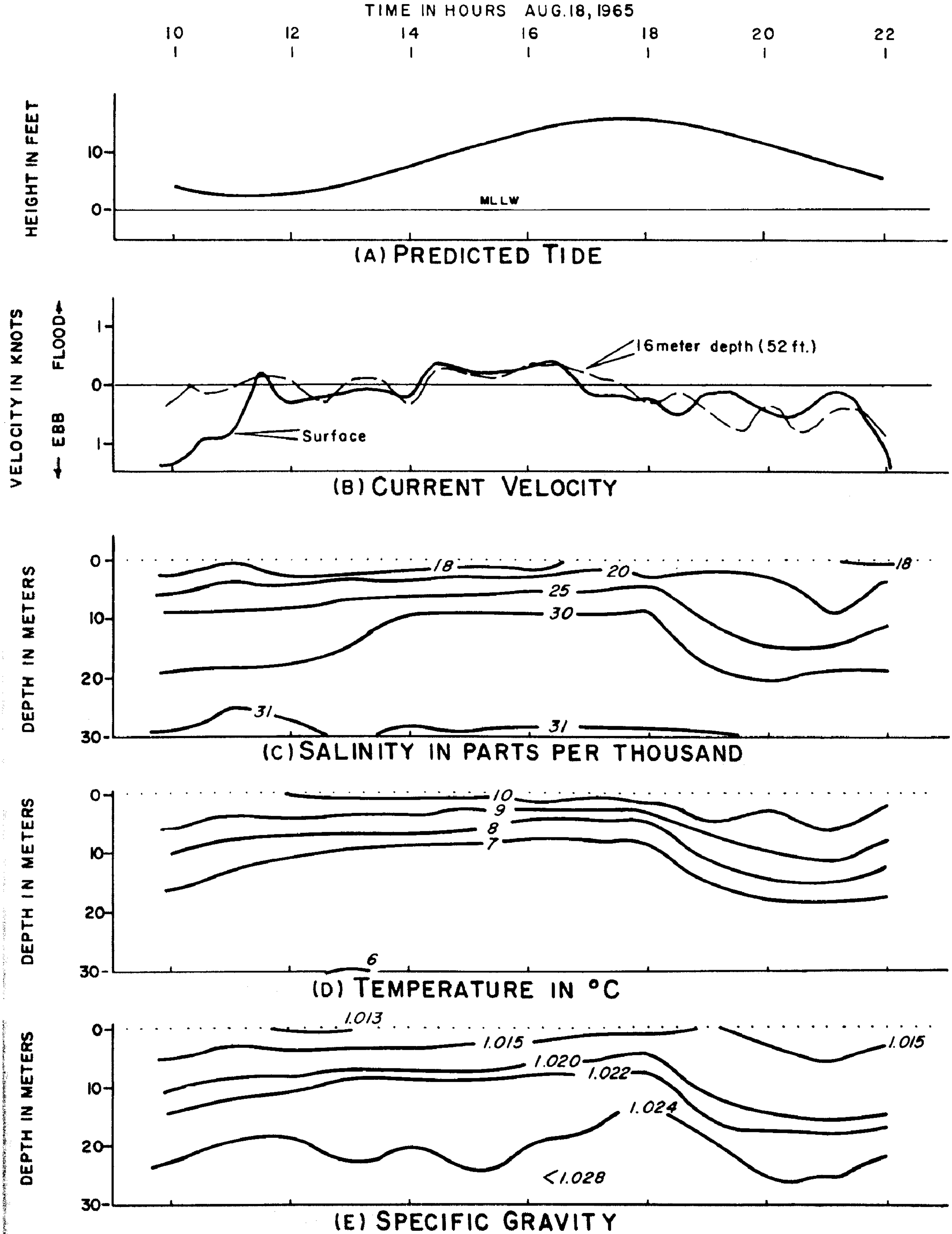

FIGURE 1-6. Patterns of (B) current velocity, (C) salinity, (D) temperature and (E) specific gravity observed at Station 2 on August 18, 1965.

FIGURE 1-7. Strength of flood surface current pattern based on float studies conducted August 18-20, 1965.

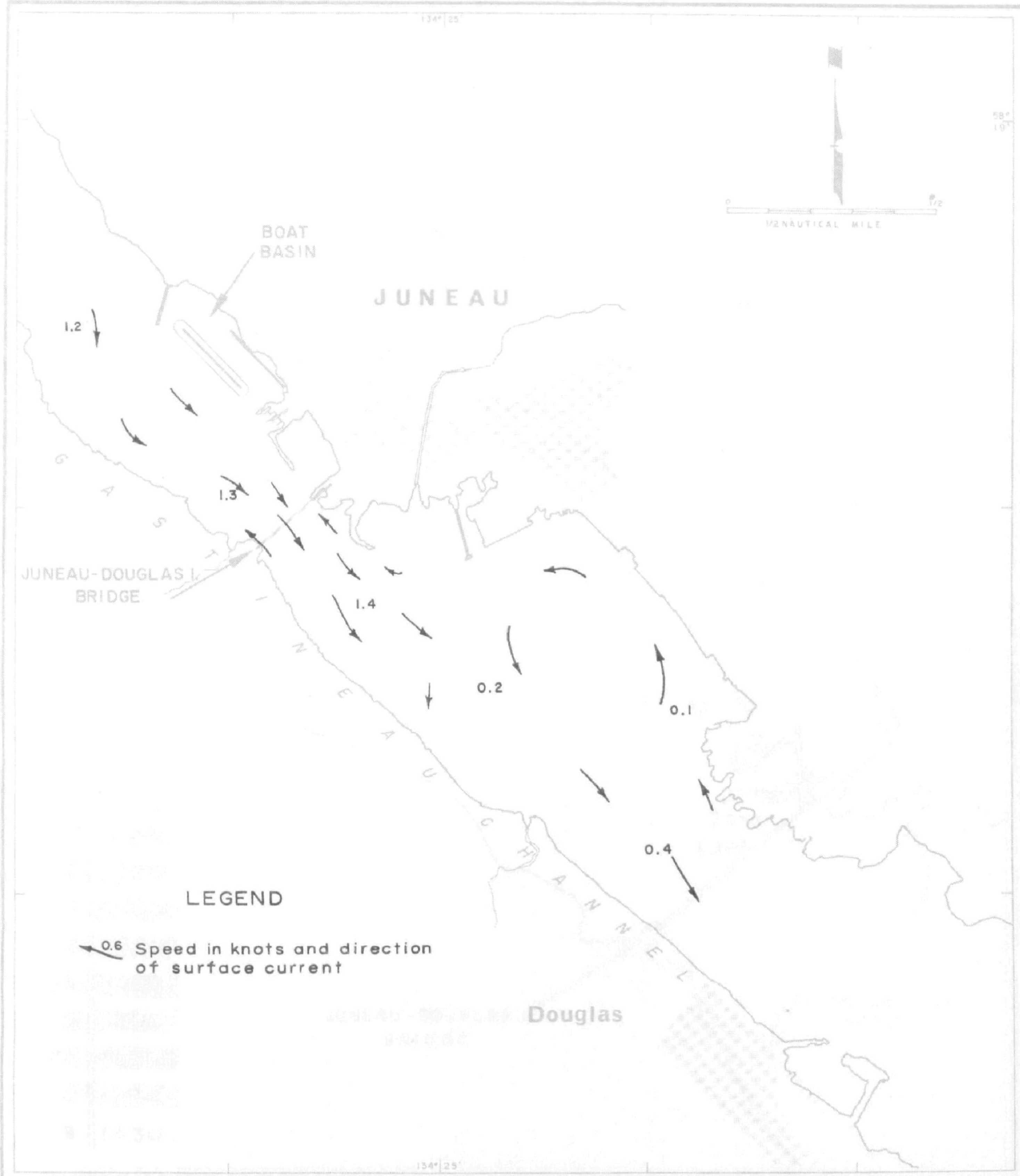

FIGURE 1-8. Strength of ebb surface current pattern based on float studies conducted August 18-20, 1965.

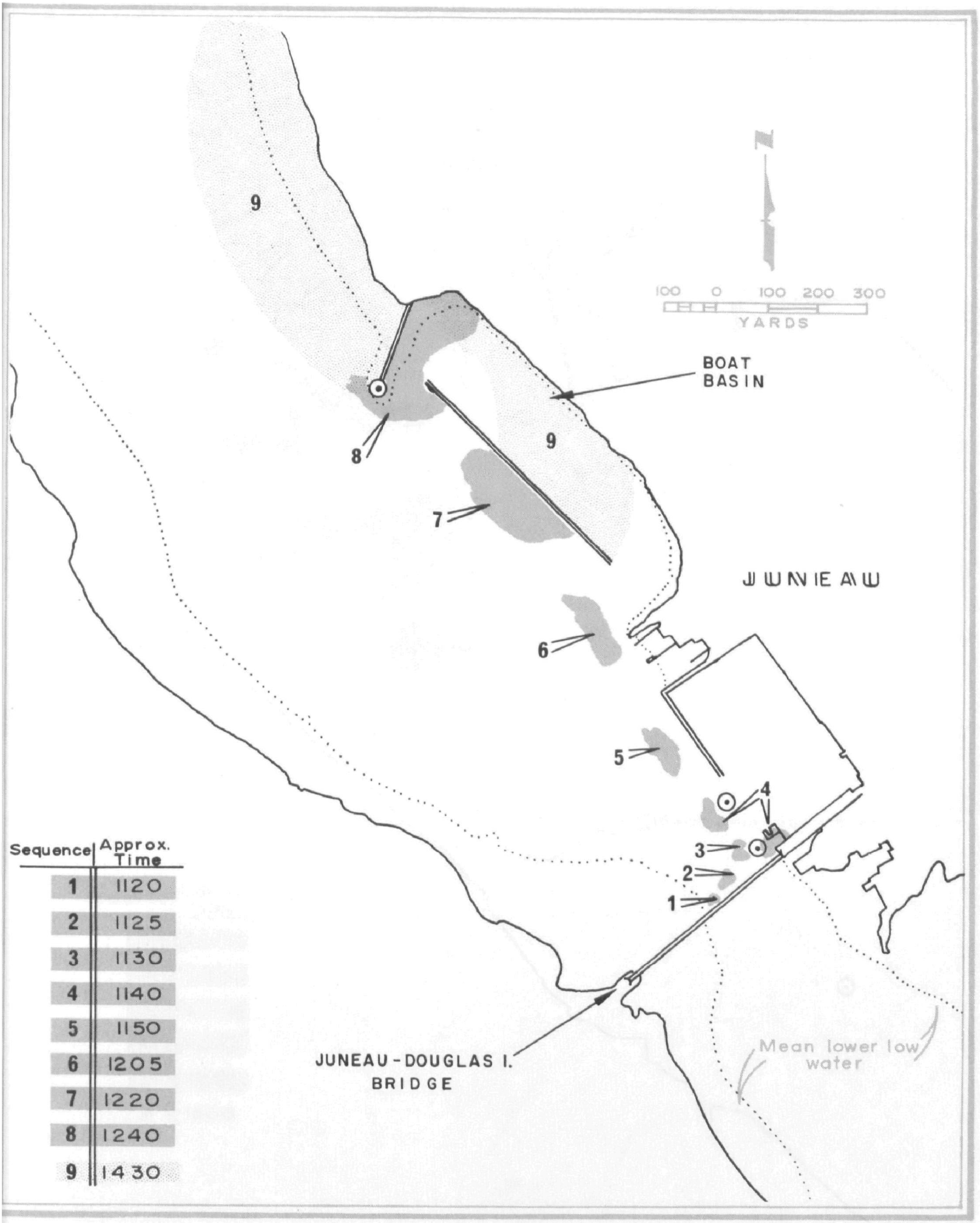

FIGURE 1-9. Sketch of successive positions of a surface dye-release during a flood tide on August 17, 1965.

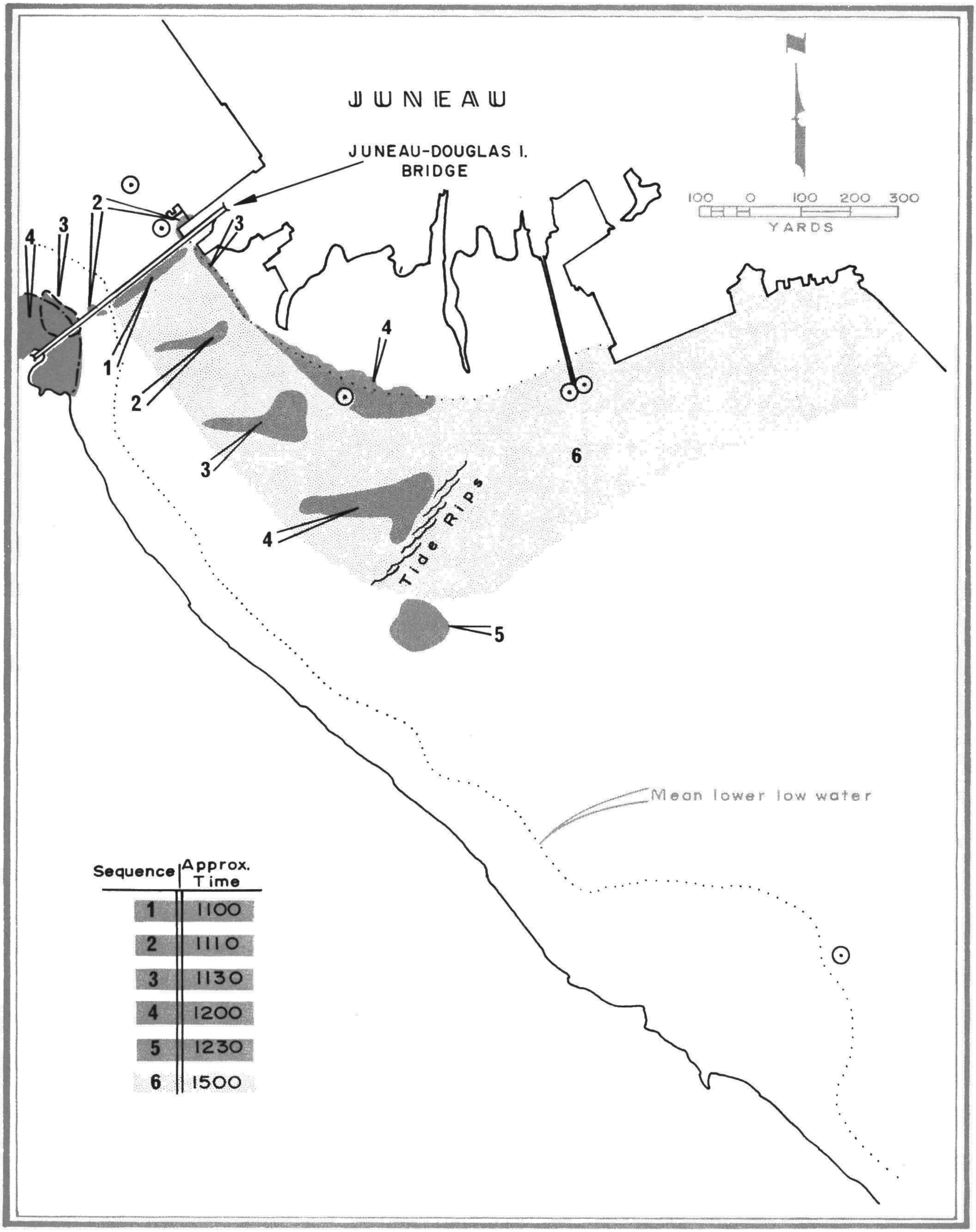

FIGURE 1-10. Sketch of successive positions of a surface dye-release during an ebb tide on August 20, 1965.

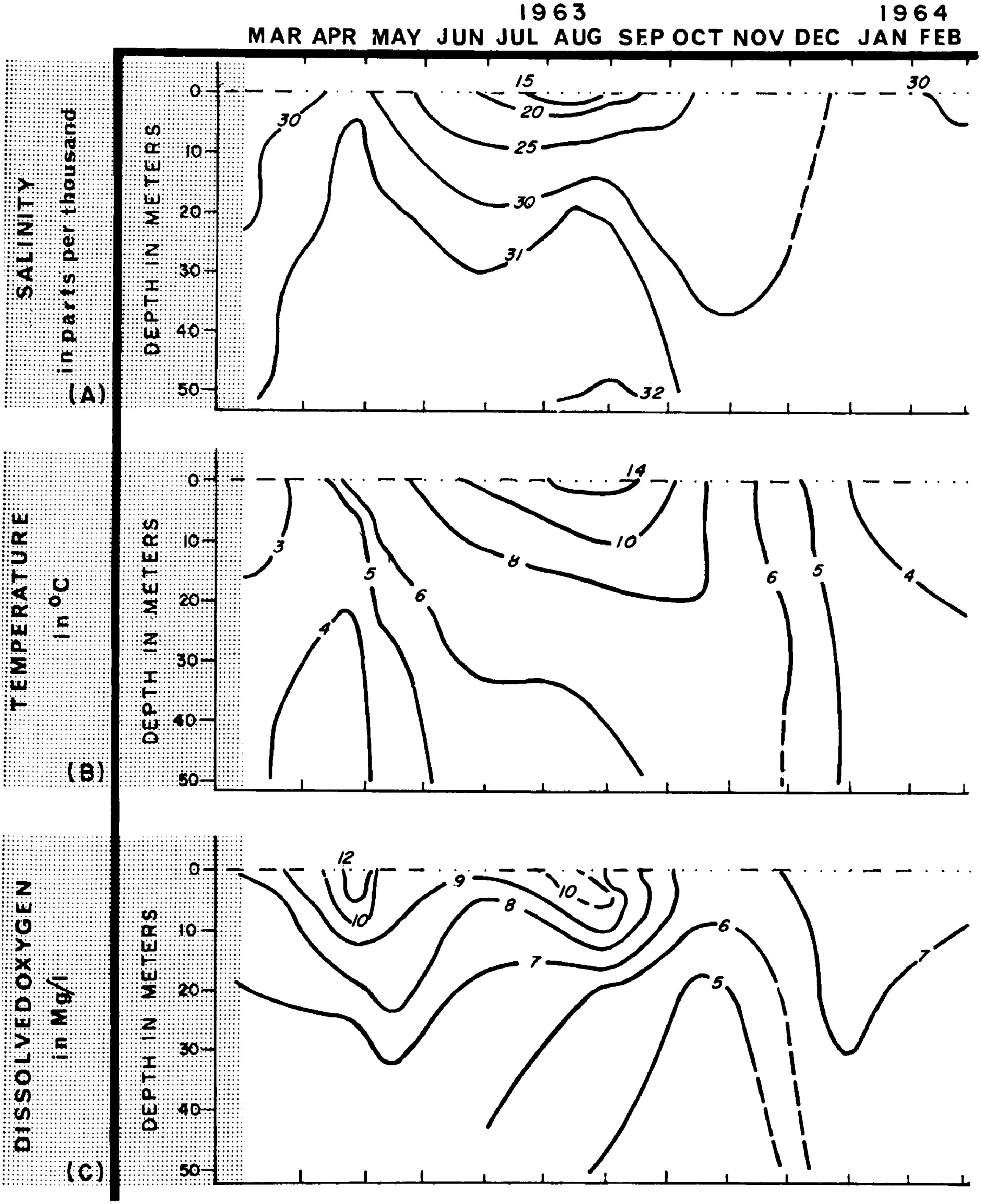

FIGURE 1-11. Annual cycles of (A) salinity, (B) temperature and (C) dissolved oxygen for a sampling station in outer Auke Bay; data provided by U. S. Bureau of Commercial Fisheries.

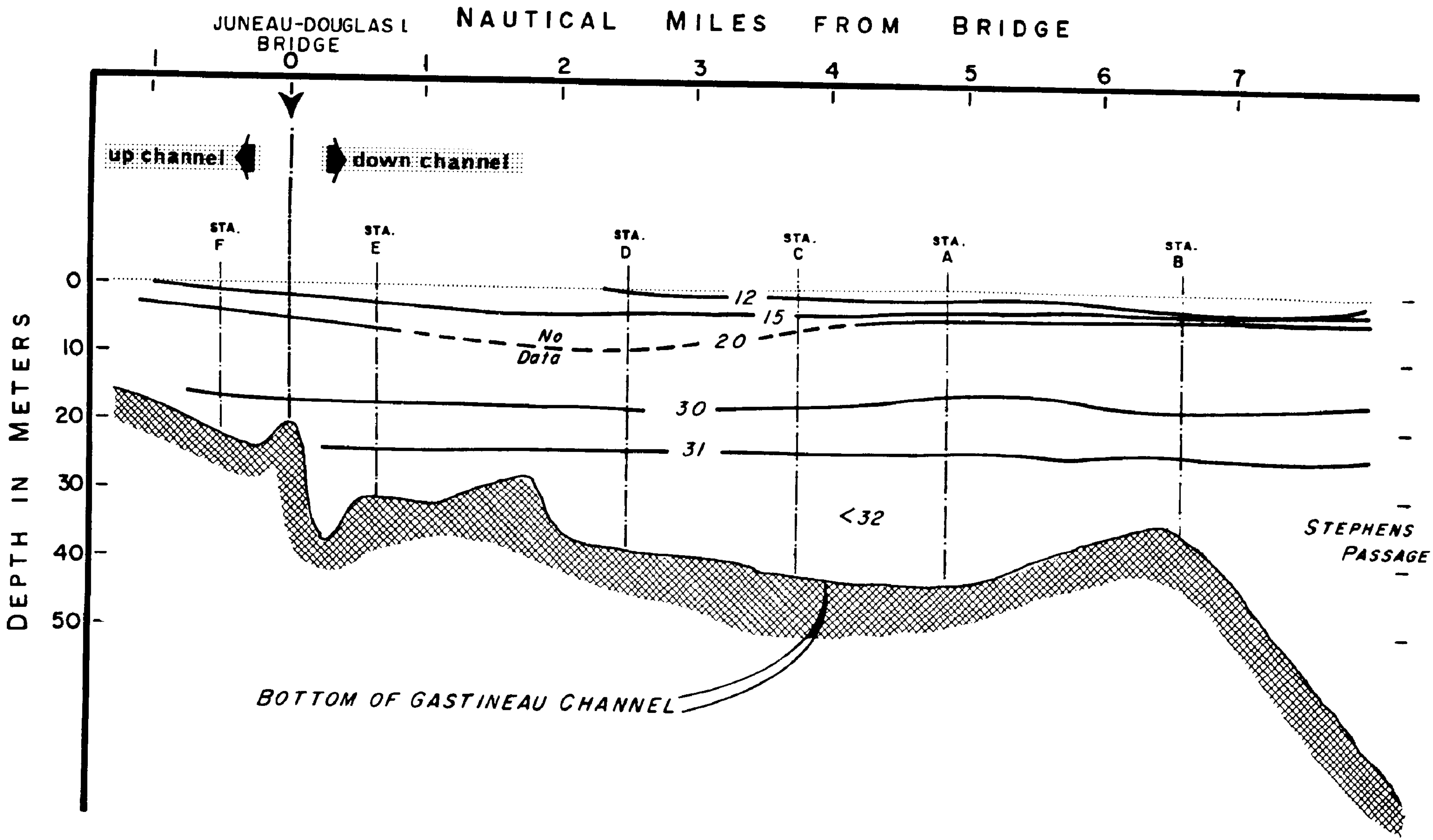

FIGURE 1-12. Observed pattern of salinity distribution in Gastineau Channel near high-water slack on August 20, 1965.

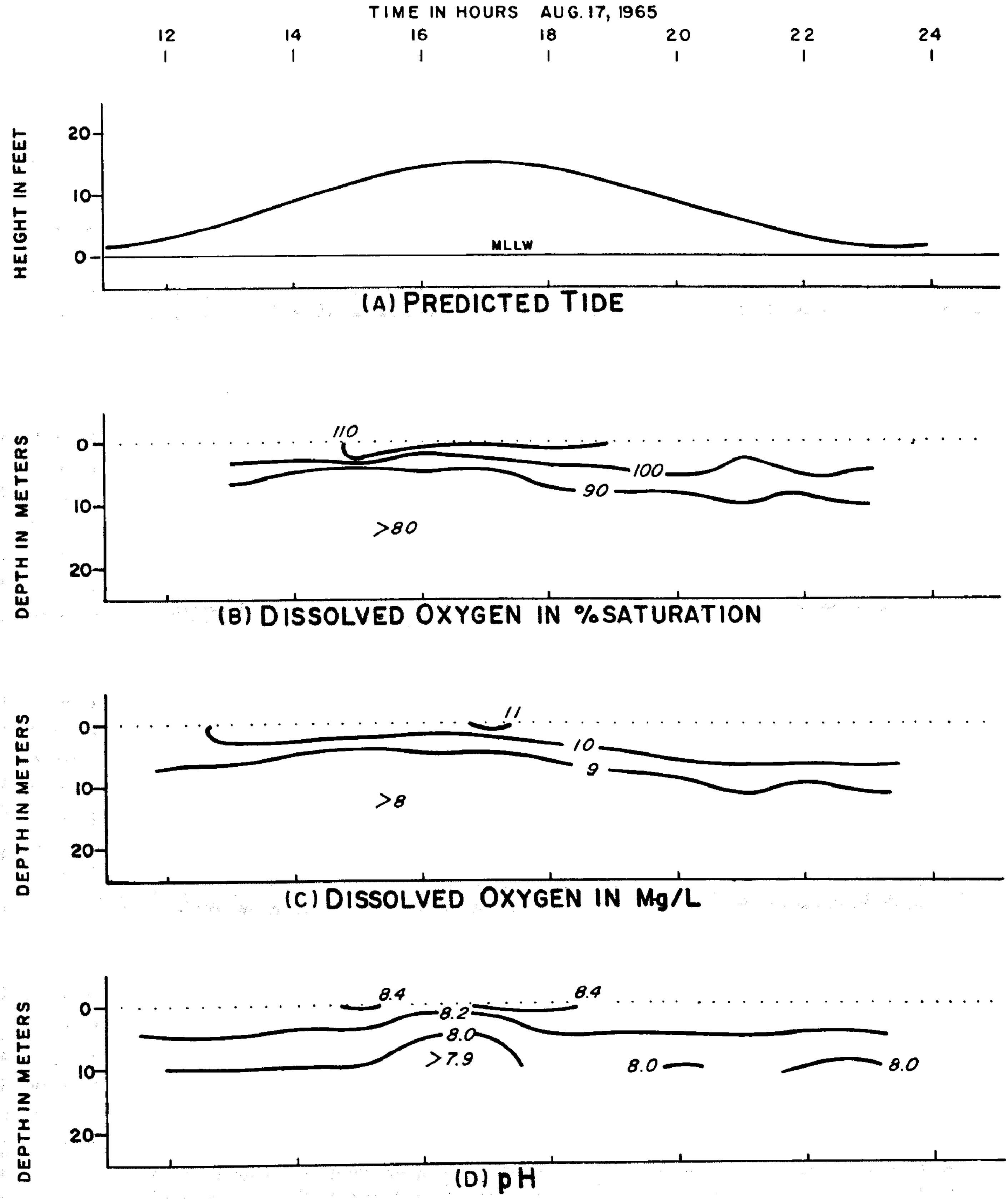

FIGURE 1-13. Patterns of (B) dissolved oxygen in percent saturation, (C) dissolved oxygen in milligrams per liter, and (D) pH at Station 1 on August 17, 1965.

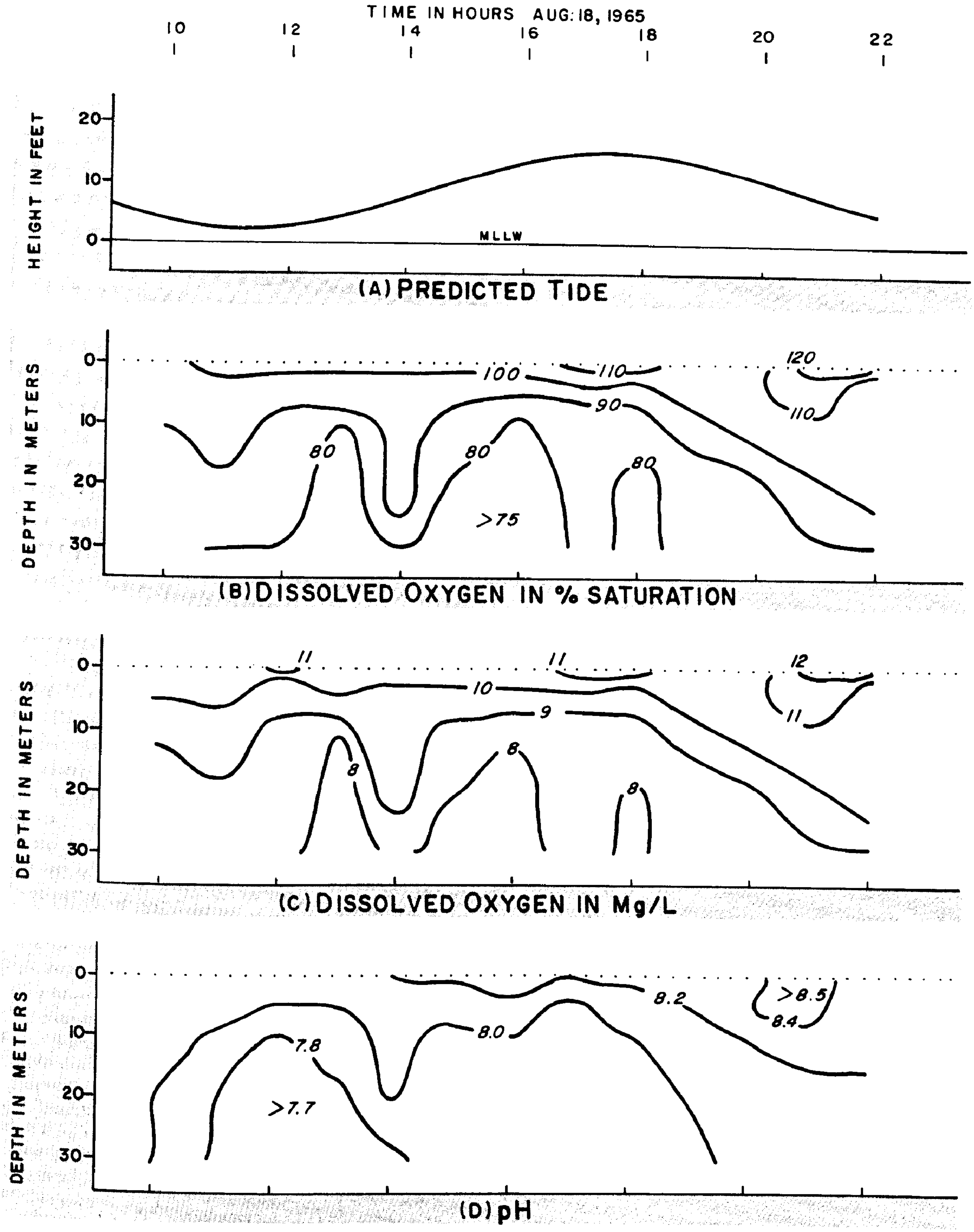

FIGURE 1-14. Patterns of (B) dissolved oxygen in percent saturation, (C) dissolved oxygen in milligrams per liter and (D) pH at Station 2 on August 18, 1965.

CHAPTER 2

FRITZ COVE STUDY

August 21-25, 1965

STUDY OBJECTIVES

Objectives of the Fritz Cove field studies were to determine water circulation and water quality patterns which would be pertinent to consideration of the area as a possible pulp mill location site.

The field studies were designed to give primary consideration to three critical points:

1. Describe basic tidal circulation in the Cove.
2. Describe current and water quality patterns in the southeastern corner of the Cove. This was considered to be the most likely area of initial consideration for location of the proposed pulp mill.
3. Determine if wastes discharged into Fritz Cove would also circulate into Auke Bay.

AREA DESCRIPTION

Fritz Cove is a semi-enclosed embayment of Stephens Passage situated between the mainland and Douglas Island (see Figure 1-1)*. Depths vary from about 110 meters at its entrance connection with Stephens Passage to the extensive exposed inner tideflats separating Fritz Cove from Gastineau Channel. Depth contours are shown on Figure 2-1. The approximate surface area of the Cove at low tide is 2.5 square miles. There is a small mid-cove connecting channel into Auke Bay. The combined surface area of Fritz Cove and adjacent Auke Bay is about 9 square miles.

Fritz Cove receives freshwater discharge from both Mendenhall River and Fish Creek (Figure 2-1). Mendenhall River flow varies from wintertime base flows of about 100 cfs (1) to summer freshet mean daily flows of at least 6,900 cfs (4). Summer freshets are associated with melting of snow and ice from Mendenhall Glacier located about 4 miles upstream from Fritz Cove. Fish Creek flows vary from winter base flows of less than 10 cfs to maximum mean daily flows exceeding 600 cfs (1).

*Figures follow page 31

STUDIES

Primary efforts were devoted to describing water circulation patterns in Fritz Cove.

A sampling station was occupied over a 12-hour tidal cycle on August 21, 1965, at the location shown on Figure 2-1. Station location was selected as being in the most probable area of initial consideration for a pulp mill outfall site. Measurements of salinity, temperature, DO, and pH were made at hourly intervals at the surface and the 2, 5, 10, 20, and 40 meter depths. Observations of current speed and direction were made at approximately half-hourly intervals at the surface and the 8, 16, and 24 meter depths.

Salinity and temperature at the surface were measured at 19 locations in Fritz Cove at high water slack on August 23 to describe the horizontal distribution of freshwater. Vertical distributions of salinity and temperature at 4 stations along a longitudinal mid-bay transect (Figure 2-1) were measured at both high and low water slack on August 24.

Current float studies were conducted in Fritz Cove on August 21, 23-25. Drogues were released at various locations and depths during both flood and ebb tides.

A surface release of Rhodamine B dye was made at the inner end of Fritz Cove on August 22. Subsequent dye distribution patterns were monitored in the Fritz Cove-Auke Bay area on August 23-24. A similar release was made on August 24 and monitored on August 24-25.

METHODS

All methods used in the Fritz Cove studies were essentially the same as those previously described for the Gastineau Channel investigations (see Chapter 1).

RESULTS

WATER CIRCULATION

Mendenhall River was in freshet condition during the period studies were being conducted in Fritz Cove. Glacial melt water from the river, apparent by its light color, was at times distributed in a thin surface layer which appeared to move seaward almost independent of the tide motion.

Tides and Tidal Currents. Daily tide predictions for Fritz Cove are listed by U. S. Coast and Geodetic Survey (3). The mean and diurnal tide ranges are 13.5 feet and 15.9 feet, respectively. Examination of U. S. Geological Survey tidal observation data (5) shows actual tides to be essentially as predicted. Current predictions are not listed for Fritz Cove.

Currents measured at the Fritz Cove sampling station were slow and very erratic at all depths, and appeared to result from variable nearshore eddies. Current velocity at the surface and 8 meter depth did not exceed 0.2 knots. Deeper velocities were mostly under 0.05 knots. No discernible pattern of either speed or direction was evident at any depth.

The accelerated outflow effect of freshet waters near the surface in Fritz Cove occurs for only a relatively short period each year (weeks) and was not considered representative of conditions which would be critical to location of a pulp mill waste outfall. For this reason most float studies were conducted at the 3-meter depth to better approximate basic tidal circulation.

Tidal circulation in Fritz Cove is effected by filling and emptying tidal currents, freshwater discharge, and tidal currents in Stephens Passage. These factors, coupled with a wide and deep basin geometry and a middle connection to Auke Bay, result in tidal circulation characterized by slow, wandering currents which vary with depth. Migrating tide-rips, with considerably different water motion on each side, were frequently observed on the southern side of the Cove during a change in tide.

Although a predominant flood or ebb pattern was not particularly well-defined at any given time, composite estimates of such patterns were possible on the basis of several float studies. These are shown for a "strength of flood" and "strength of ebb" condition at the 3-meter depth on Figures 2-2 and 2-3, respectively. Currents at 8-meter and 16-meter depths had essentially the same pattern but less than half the speed.

A true slack tide condition did not develop in the Cove. Rather, currents would wander from one basic pattern to the next over the tide change. The current pattern change took an hour or more to develop and lagged the high or low tide height by one or two hours. This is a shift toward the tidal current timing in Stephens Passage. Based on U. S. Geological Survey data (5), tidal currents in the Fritz Cove portion of the tide flat connection to Gastineau Channel slack and flow essentially with the timing of the tide.

One notable feature of the current patterns (Figures 2-2 and 2-3) is that currents along the inner quarter of the southern shore are predominantly inward during both flood and ebb tide conditions.

Salinity-Freshwater Relationships. Near-surface salinities in Fritz Cove were extremely variable, both from time-to-time and place-to-place, due to Mendenhall River freshet condition and the wandering nature of the tidal currents. Freshet waters were detectable in the Cove to some extent by color and by depression of surface salinity below the minimum of about 13 parts per thousand observed in Stephens Passage. The Mendenhall River plume was observed most frequently on the northern (ebb) side of Fritz Cove and was generally layered above 2 meters in depth. Vertical salinity distribution below the 2-meter depth did not greatly reflect that lying above it.

Salinity, temperature and density observed at Station A for the 12-hour period on August 21 are shown on Figure 2-4. The surface salinity pattern in Fritz Cove as measured at high tide on August 23 is shown on Figure 2-5. High and low tide vertical salinity distributions as measured along a mid-Cove transect on August 24 are shown on Figure 2-6. These patterns are considered representative of conditions during high Mendenhall River runoff. An annual cycle of salinity and temperature for a station in nearby Auke Bay was shown in Chapter 1 (Figures 1-1 and 1-11B and C).

Net Circulation. Net transport of surface waters in Fritz Cove must be seaward due to the Mendenhall River inflow. Based on salinity observations this effect is most prominent along the northern side of the Cove. Beneath the fresher layer during periods of high Mendenhall River discharge (summer), and for all waters in the Cove in the absence of high discharge (winter months), any net transport must result primarily from tidal or wind driven circulation. Some indication of a net inward predominance of tidal currents near the southern shore at the inner end of the Cove was noted from the 3 meter depth float studies (Figures 2-2 and 2-3).

Successive dye patterns observed following the surface releases of Rhodamine B at the inner end of the Cove on August 22 and 24 are shown on Figures 2-7 through 2-9 and 2-10 through 2-12, respectively. Contour values shown are in fluorometer units which approximate relative dye concentration. Absolute concentration could not be defined because of variable background readings due to suspended particles in the water. This background varied from 5 to 25 fluorometer units in Stephens Passage and Mendenhall River, respectively. Background values monitored at the surface in Auke Bay prior to the dye releases were less than 10 fluorometer units, with some apparent effect from suspended particles in Auke Creek discharge. Any dilution of freshwater discharge with seawater would cause a corresponding reduction in background reading.

Some features noticed in examination of the dye sketches (Figures 2-7 through 2-12) are:

1. Water from the inner end of Fritz Cove is not completely replaced each tidal cycle but is moved out in patches over a period of several tidal cycles.
2. Initial displacement of the patches from the inner end of the Cove is counterclockwise, followed by primary movement outward along the northern side of the Cove to mid-bay. Final movement out of the Cove is predominantly back toward the southern shore as suggested by the ebb current pattern (Figure 2-3).

3. Dye was definitely still present in Fritz Cove after about 4 tidal cycles (August 22-24).

4. Fluorometer readings in Auke Bay following both dye releases were above natural background values expected. Those shown on Figures 2-11 and 2-12 (August 24 dye release) are considered definite indication of dye movement from inner Fritz Cove into Auke Bay.

Dye movements shown should be considered representative of surface conditions during Mendenhall River freshet periods. Rate of net transport during other periods and at depth at all times would be reduced.

WATER QUALITY

Dissolved oxygen content, in terms of percent saturation and milligrams per liter, and pH values measured at Station A on August 21 are shown on Figure 2-13. An annual cycle of dissolved oxygen for a station in nearby Auke Bay was presented in Chapter 1 (Figure 1-11).

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Physical conditions in Fritz Cove during this study were representative of a relatively short period of the annual cycle, particularly with respect to the observed accelerated surface outflow due to Mendenhall River freshet discharge. However, certain general features of Fritz Cove were described which are important to consideration of the area as a possible pulp mill effluent receiver:

1. Tidal circulation in Fritz Cove is slow and wandering with most of the motion occurring near the surface. Inside the Cove, flood motion appears strongest along the southern side and ebb motion appears strongest toward the northern side.
2. A counterclockwise eddy develops at the inner end of the Cove during ebb tide; thus, transport is directed predominantly inward along the inner southern shore during both flood and ebb tides.
3. Water from the inner end of the Cove is not completely exchanged in a single tidal cycle but is circulated in the Cove and flushed outward over a period of days.
4. Wastes discharged to surface waters within the Cove would eventually disperse into Auke Bay.

In addition, the annual cycle of salinity and temperature (Figure 1-11A and B) indicates that the area waters are stably stratified (density increases significantly with depth) during the period from about May to October and are near-neutral or unstable during the remainder of the year. A stable stratification inhibits vertical mixing and would tend to confine surface-discharged wastes near the surface and deep-discharged wastes at depth. Conversely, a neutral or unstable condition facilitates vertical mixing of the water column.

Consideration of Fritz Cove as a possible location for a pulp mill must include evaluation of its potential effect on marine resources of the area. One aspect of primary importance in the Fritz Cove-Auke Bay area is the presence of the U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries Laboratory, located on Auke Bay. This laboratory engages in important comprehensive basic and applied fisheries research programs in Fritz Cove-Auke Bay and adjacent waters. Presence of pulp mill pollution in the area may jeopardize much of the laboratory's potential and invalidate considerable portions of basic programs already under way.

Sulfite waste liquor (SWL) concentration is generally used as an indicator of the presence of pulp mill wastes in natural waters. Bioassay studies conducted recently by this office in conjunction with investigations of pulp mill pollution in Puget Sound, Washington, show that the marine biota is adversely affected by relatively low concentrations of SWL. Concentrations of 10 ppm result in a 12 percent mortality to oyster larvae.

Average SWL content in pulp mill effluent varies from about 5,000 ppm from a mill employing chemical recovery to more than 200,000 ppm from a mill with no recovery. For example, main sewer effluent from the Ketchikan Pulp Company mill at Ward Cove (described in Chapter 4) during a three-day study period averaged 34.4 million gallons per day at an SWL concentration of 7,285 ppm. If this waste were discharged and uniformly mixed within Fritz Cove it would be sufficient to raise the SWL concentration above the 10 ppm toxicity threshhold in a surface layer 10 feet deep within the first 5 hours of plant operation. There are numerous examples of the far-reaching effects of pulp mill wastes discharged to embayed coastal waters similar to those of the Fritz Cove-Auke Bay embayment of Stephens Passage:

1. Ward Cove near Ketchikan, Alaska, where SWL concentrations from the Ketchikan Pulp Company mill were observed at the surface between about 500 and 1,000 ppm within Ward Cove, up to one mile from the source, and between about 20 and 40 ppm in the adjacent waters of Tongass Narrows, more than two miles from the source (see Chapter 4).
2. Silver Bay near Sitka, Alaska, where SWL from the Alaska Lumber and Pulp Company mill was observed to generally exceed 200 ppm at the surface throughout an area of at least 10 square miles. SWL concentrations exceeding 250 ppm were observed about 3 miles from the source (see Chapter 3).
3. Everett, Washington, where combined wastes from Scott Paper Company mill and Weyerhaeuser Corporation mill are discharged to Port Gardner via a deep diffuser. SWL concentrations in the receiving waters have been observed to average over 30 ppm at a distance of 10 miles from the source.

4. Bellingham-Samish Bay, Washington, where SWL concentrations from the Georgia-Pacific Corporation pulp mill have been observed in surface waters to exceed 50 ppm at a distance of 8 miles from the source. Average SWL concentrations exceed 200 ppm over a one-square-mile area and 10 ppm over a fifty-square-mile area.

In addition to toxic effects of pulp waste on marine biota, serious water quality degradation, in terms of reduced dissolved oxygen, lowered pH, increased color, etc., usually occurs in natural waters due to the presence of such wastes (for example, see Chapters 3 and 4).

In view of (a) the apparent slow tidal circulation and lack of strong net transport of water away from the area, (b) the demonstrated dispersion of Fritz Cove water into Auke Bay, and (c) the comparable size of the approximately 9-square-mile Fritz Cove-Auke Bay system to other areas affected by pulp mill waste discharge, it is expected that discharge of pulp mill wastes within Fritz Cove would result in occurrence of waste concentrations well above the toxicity threshhold throughout the Fritz Cove-Auke Bay area.

RECOMMENDATIONS

Based on the foregoing discussion and in the interest of preserving the research potential of the Auke Bay Laboratory, it is recommended that another area be sought for location of a future pulp mill outfall.

If an alternative site is not available and Fritz Cove is selected, we recommend that consideration be given only if subject to the following:

1. The outfall be located in Stephens Passage outside the limits of circulation in the Fritz Cove-Auke Bay embayment. This should be considered only if it can be established that there is a significant net transport away from the selected site sufficient to insure dilution of waste concentration below threshhold values in any area deemed important to the marine resources.
2. The outfall be equipped with a diffuser section designed for maximum initial dilution and submerged to the depth necessary to insure containment of the buoyant waste plume below at least 30 meters depth during all degrees of density stratification likely to occur.

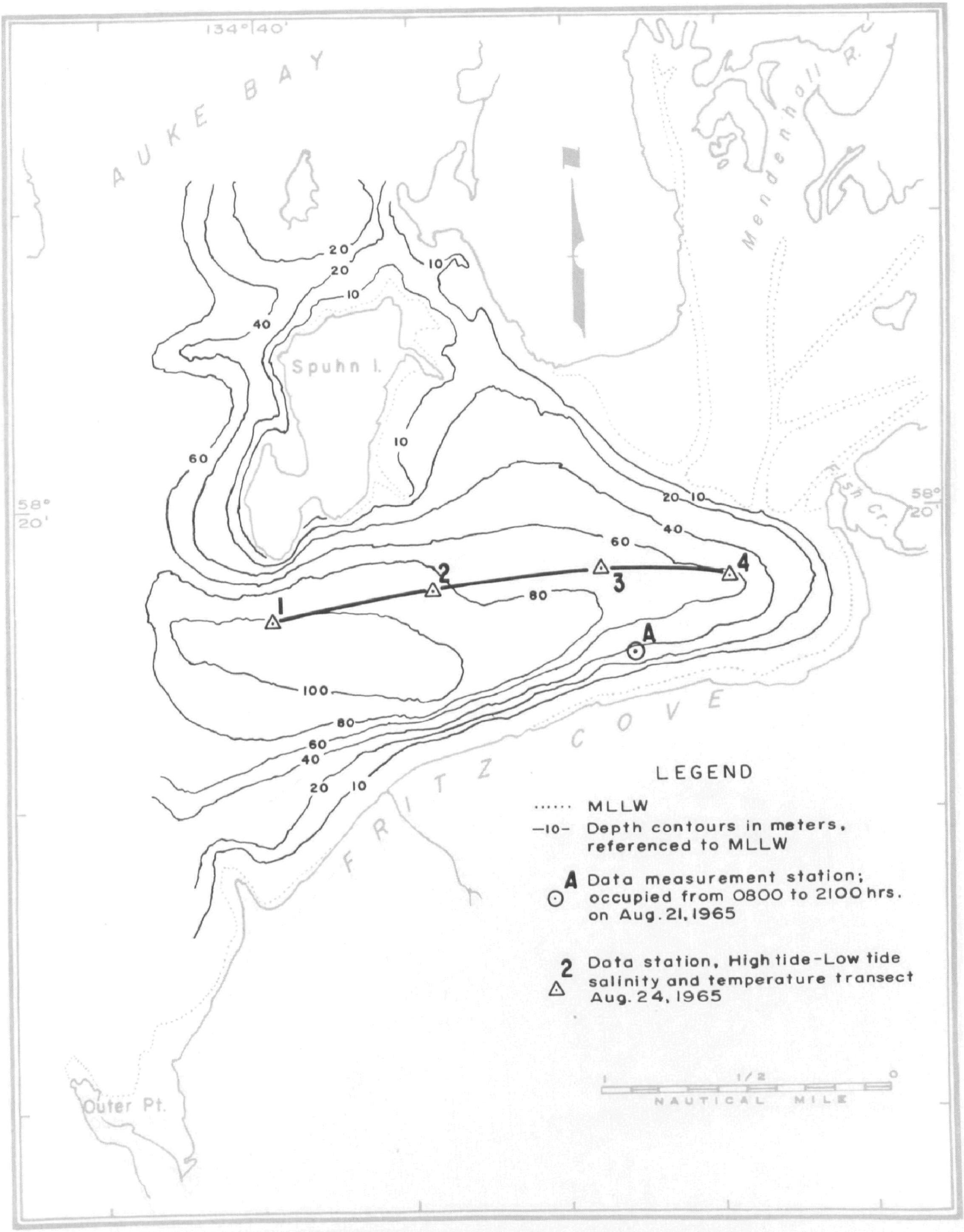

FIGURE 2-1. Fritz Cove study area and sampling locations.

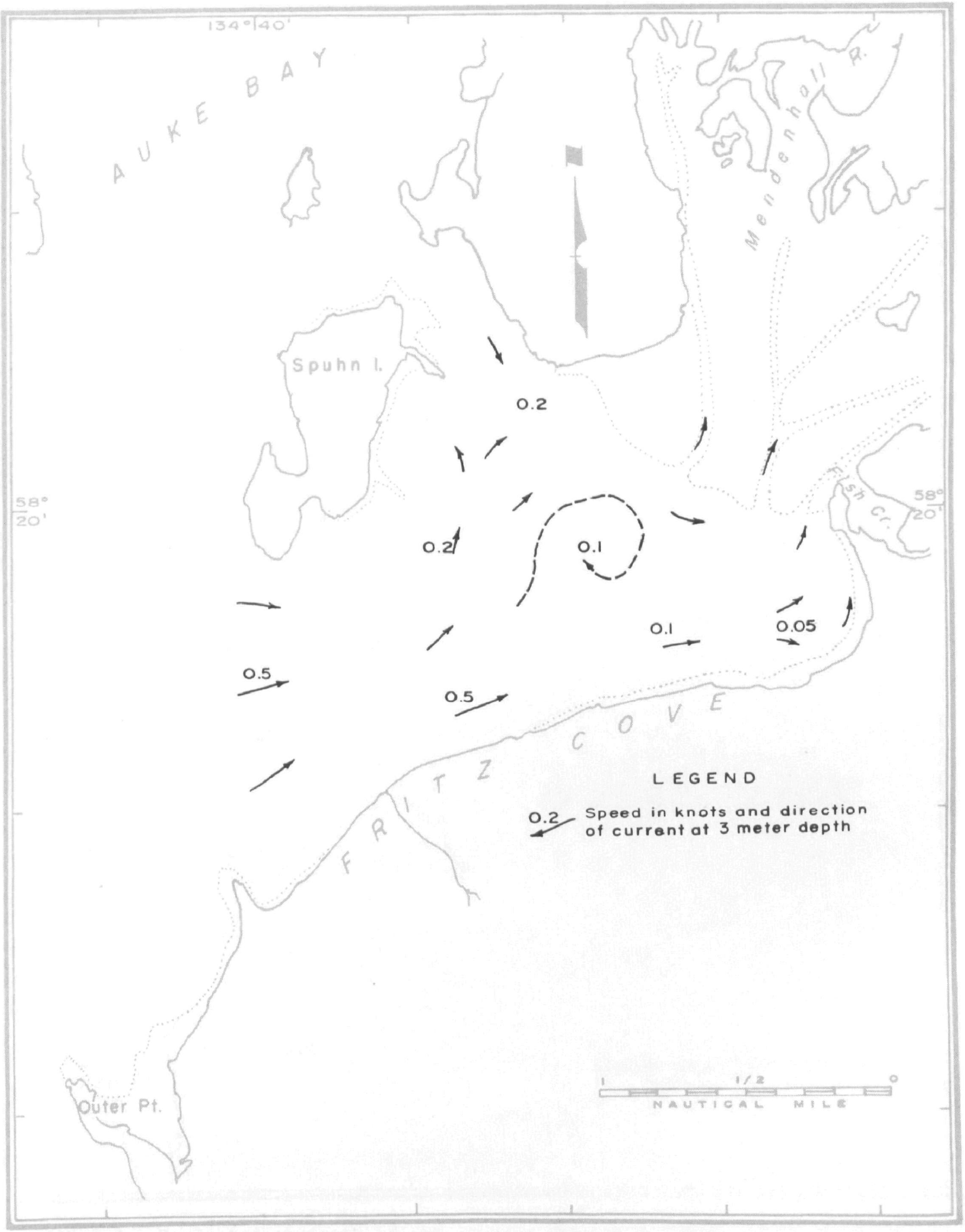

FIGURE 2-2. Estimated strength of flood current pattern at three meter depth, based on float studies conducted August 21, 23-25, 1965.

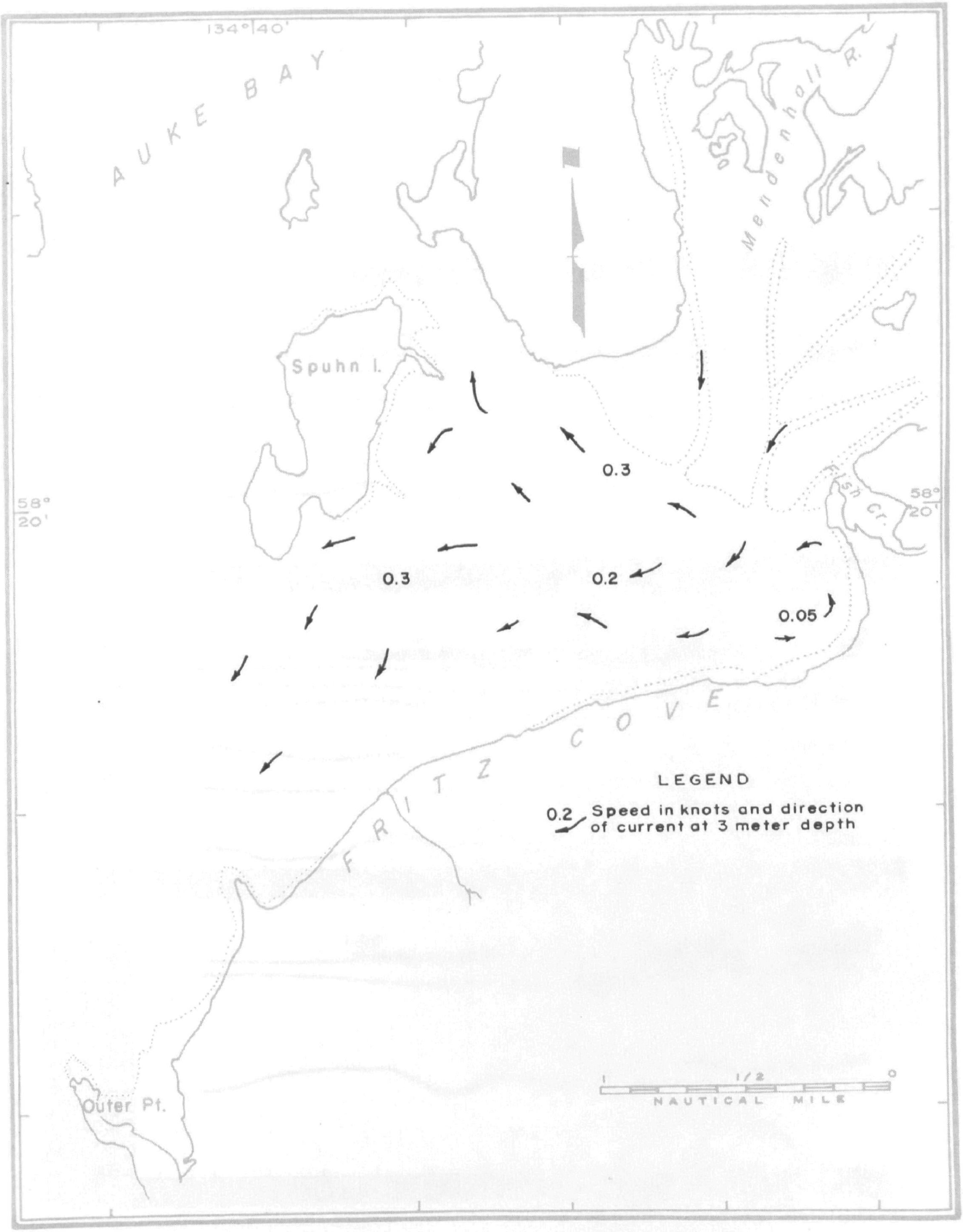

FIGURE 2-3. Estimated strength of ebb current pattern at three meter depth, based on float studies conducted August 21, 23-25, 1965.

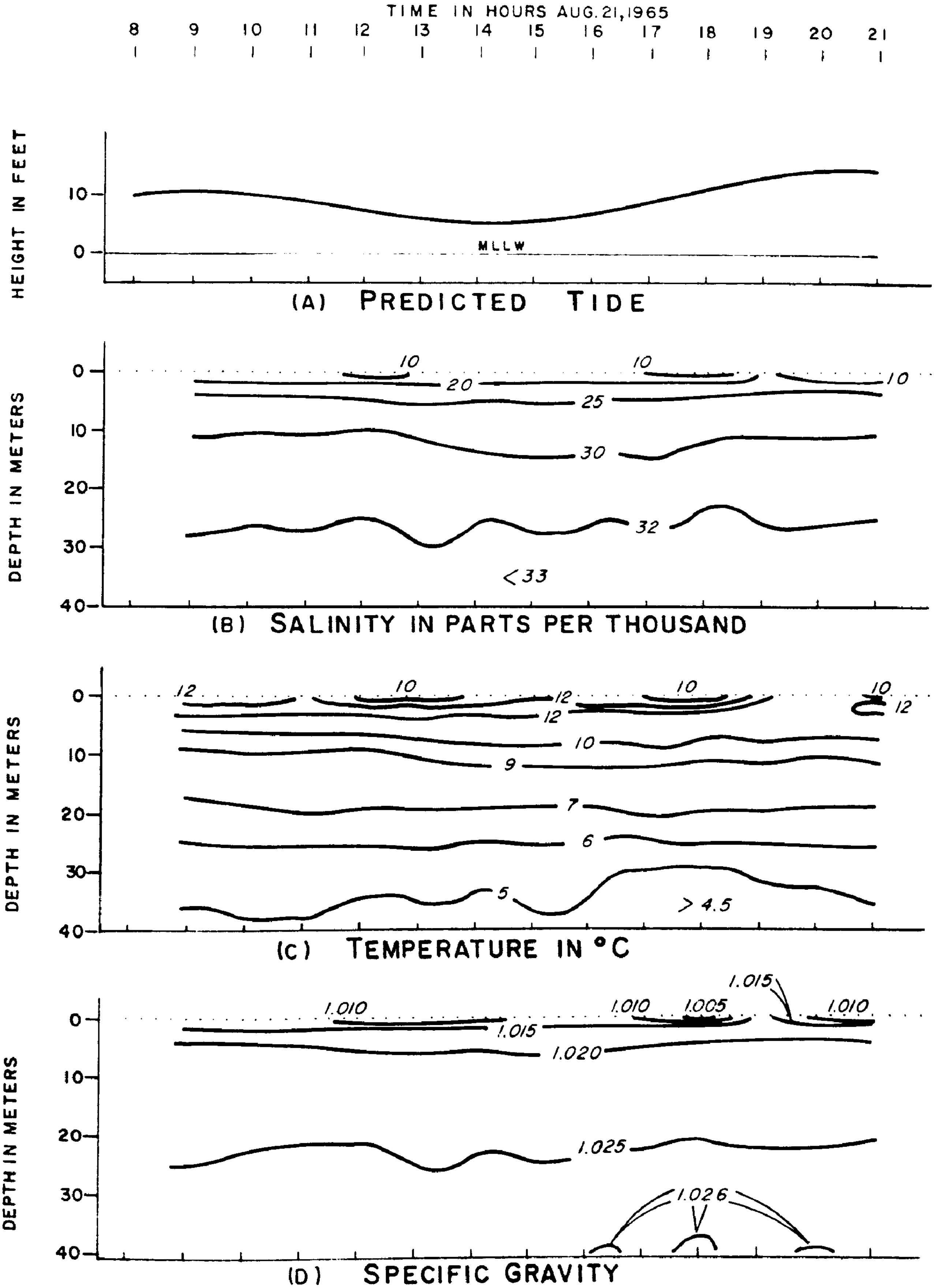

FIGURE 2-4. Patterns of (B) salinity, (C) temperature, and (D) specific gravity at sampling Station A, August 21, 1965.

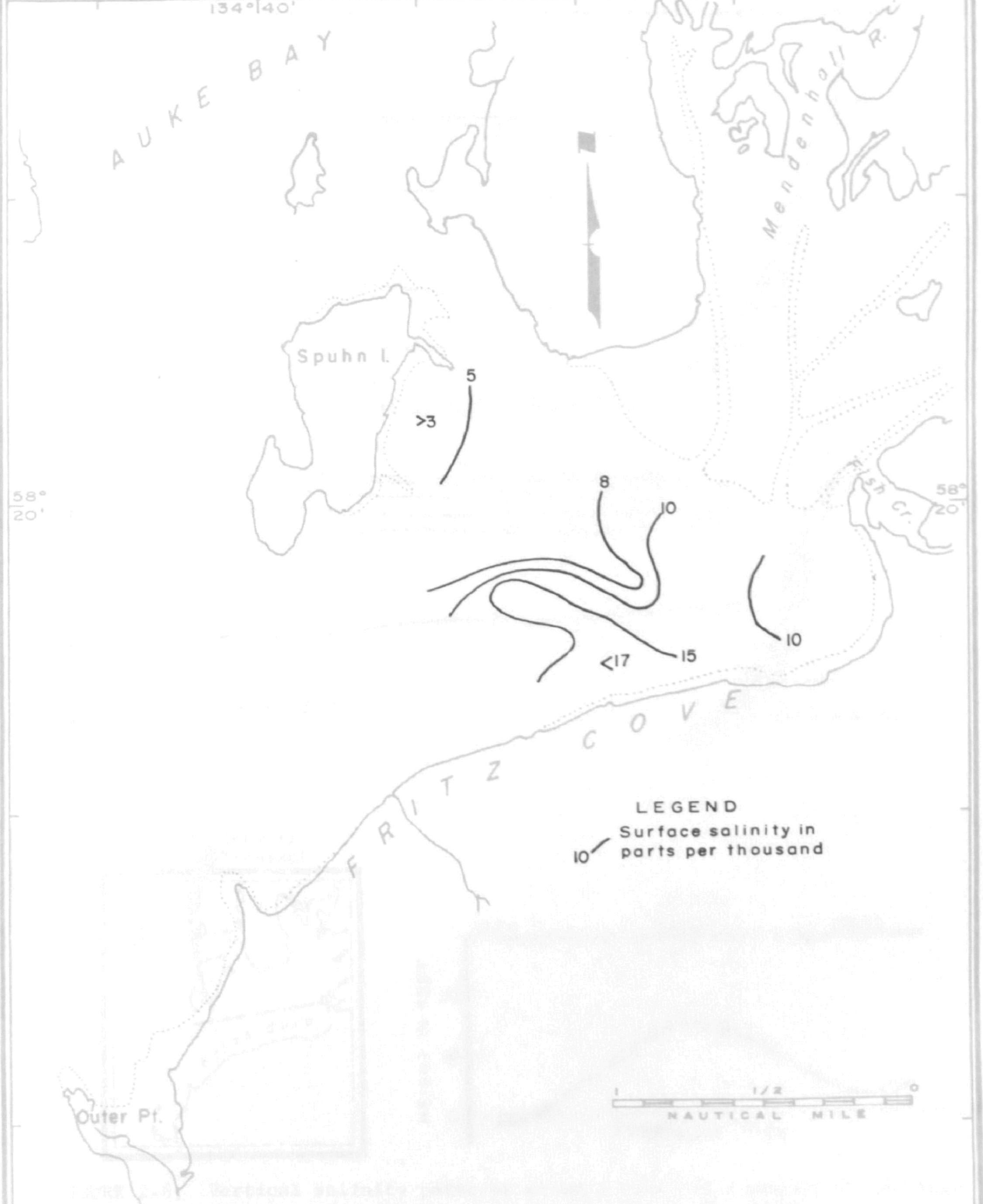

FIGURE 2-5. Pattern of surface salinity at high water slack, August 23, 1965.

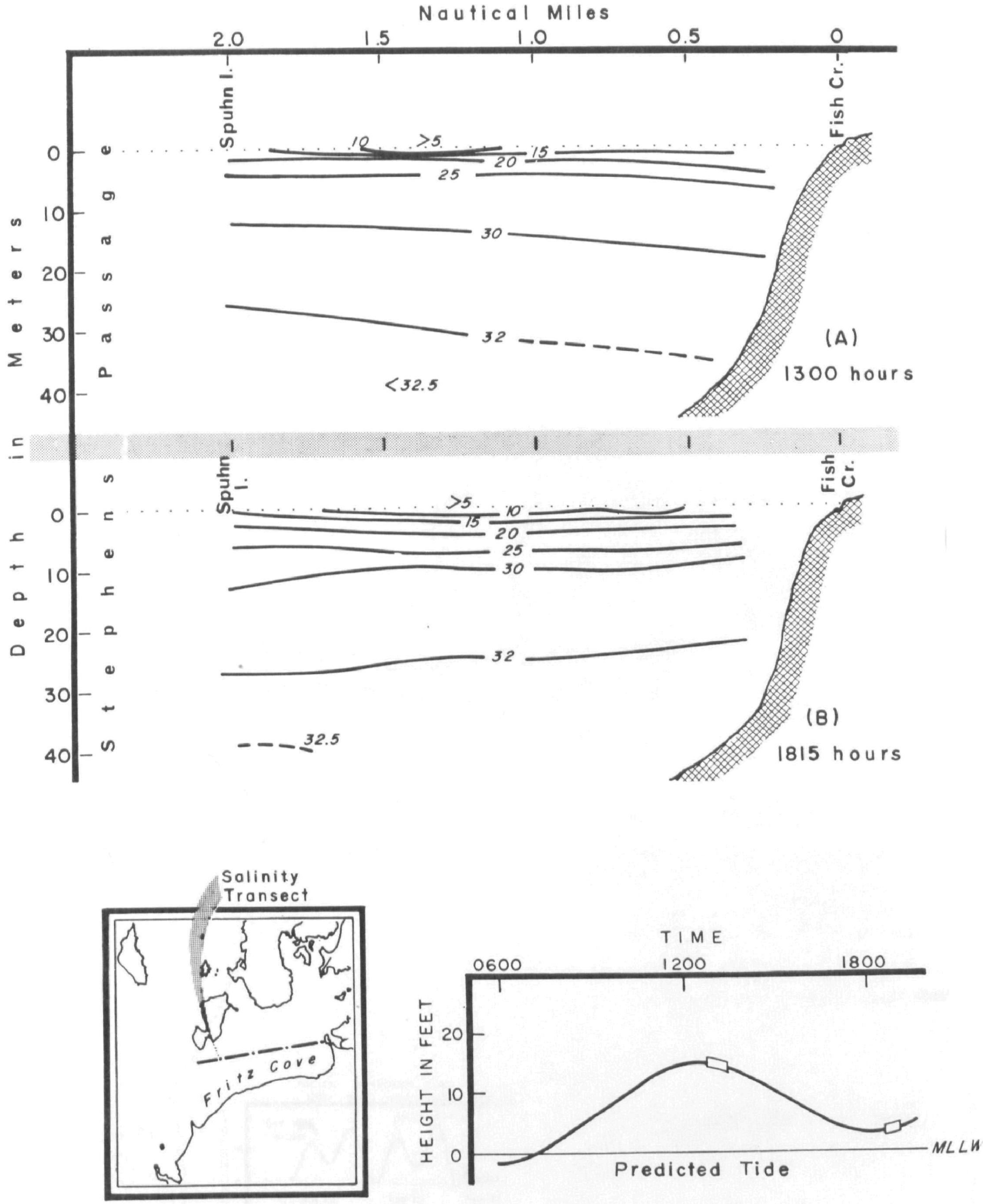

FIGURE 2-6. Vertical salinity patterns along a mid-Cove transect at (A) high water slack and (B) low water slack, August 24, 1965.

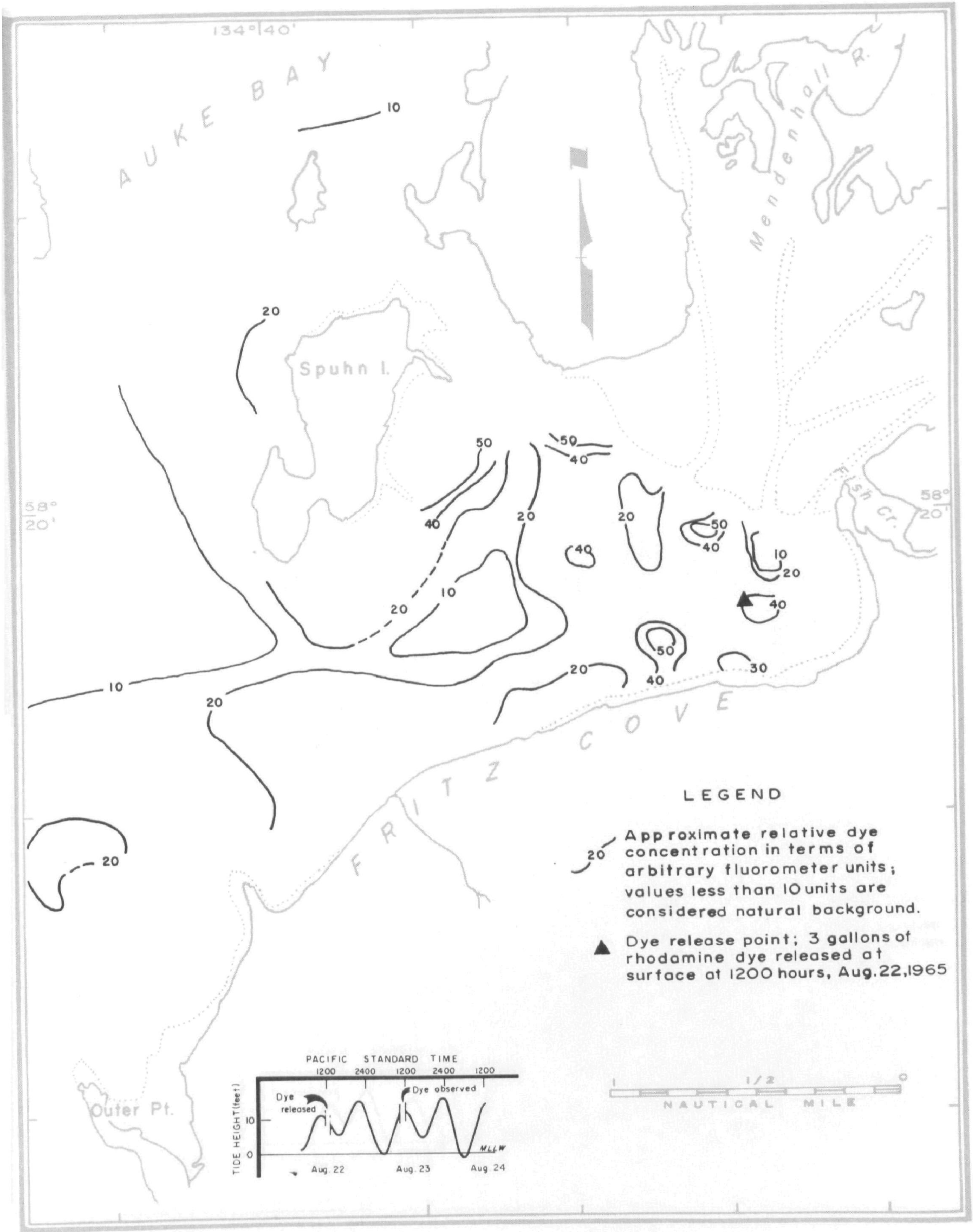

FIGURE 2-7. Surface dye dispersal pattern observed between 1030 and 1200 hours on August 23, following August 22 dye release.

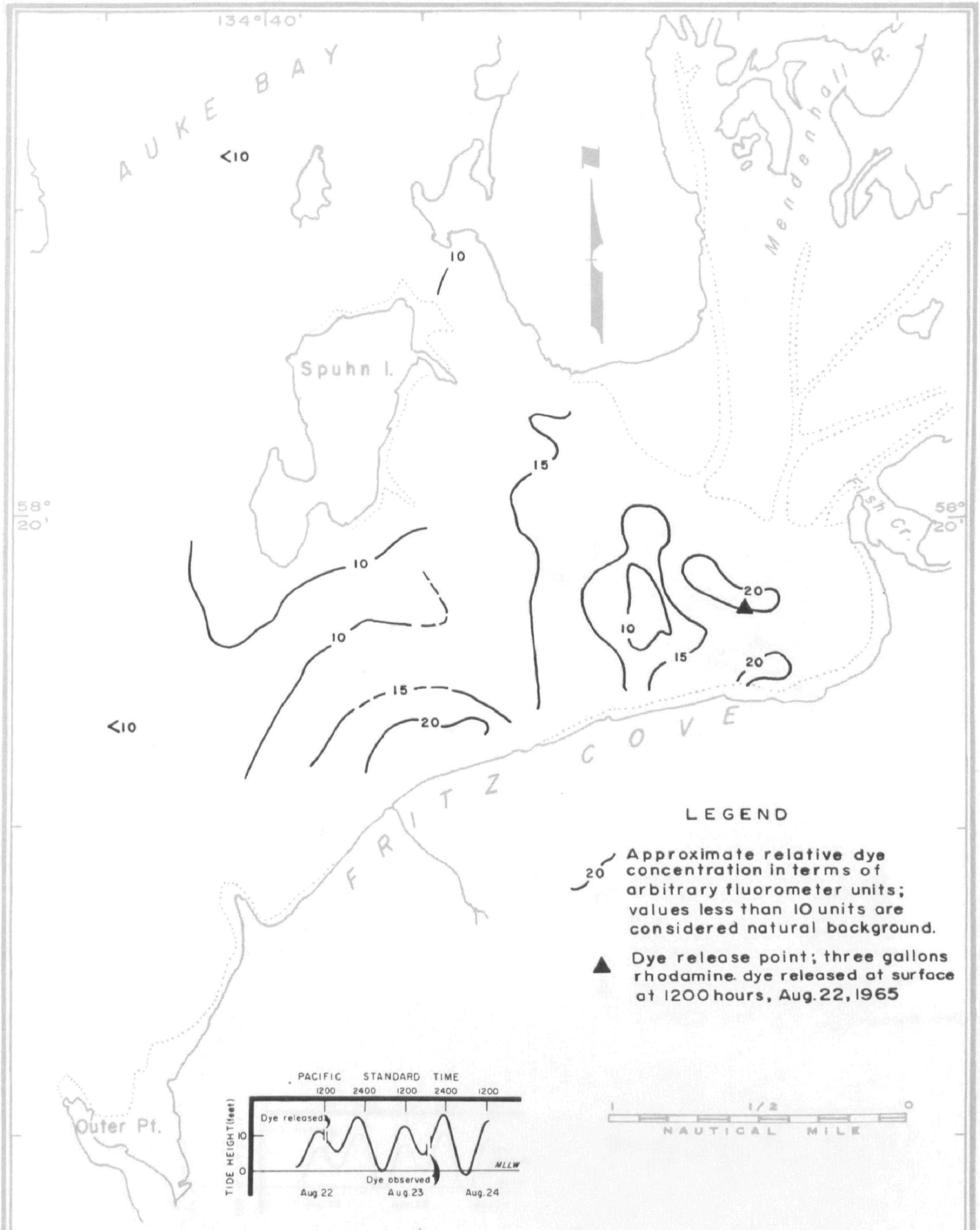

FIGURE 2-8. Surface dye dispersal pattern observed between 1830 and 1930 hours on August 23, following August 22 dye release.

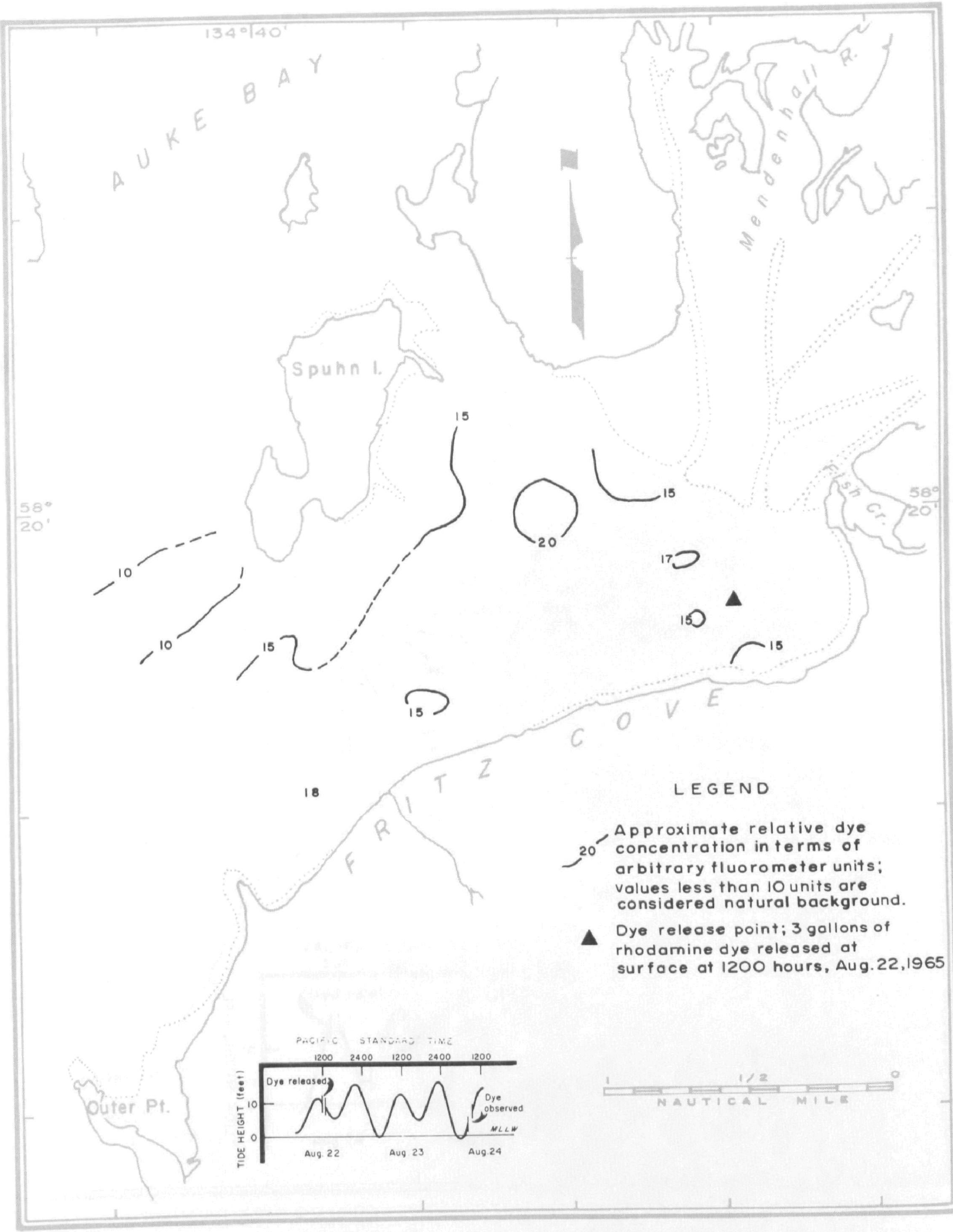

FIGURE 2-9. Surface dye dispersal pattern observed between 0830 and 0930 hours on August 24, following August 22 dye release.

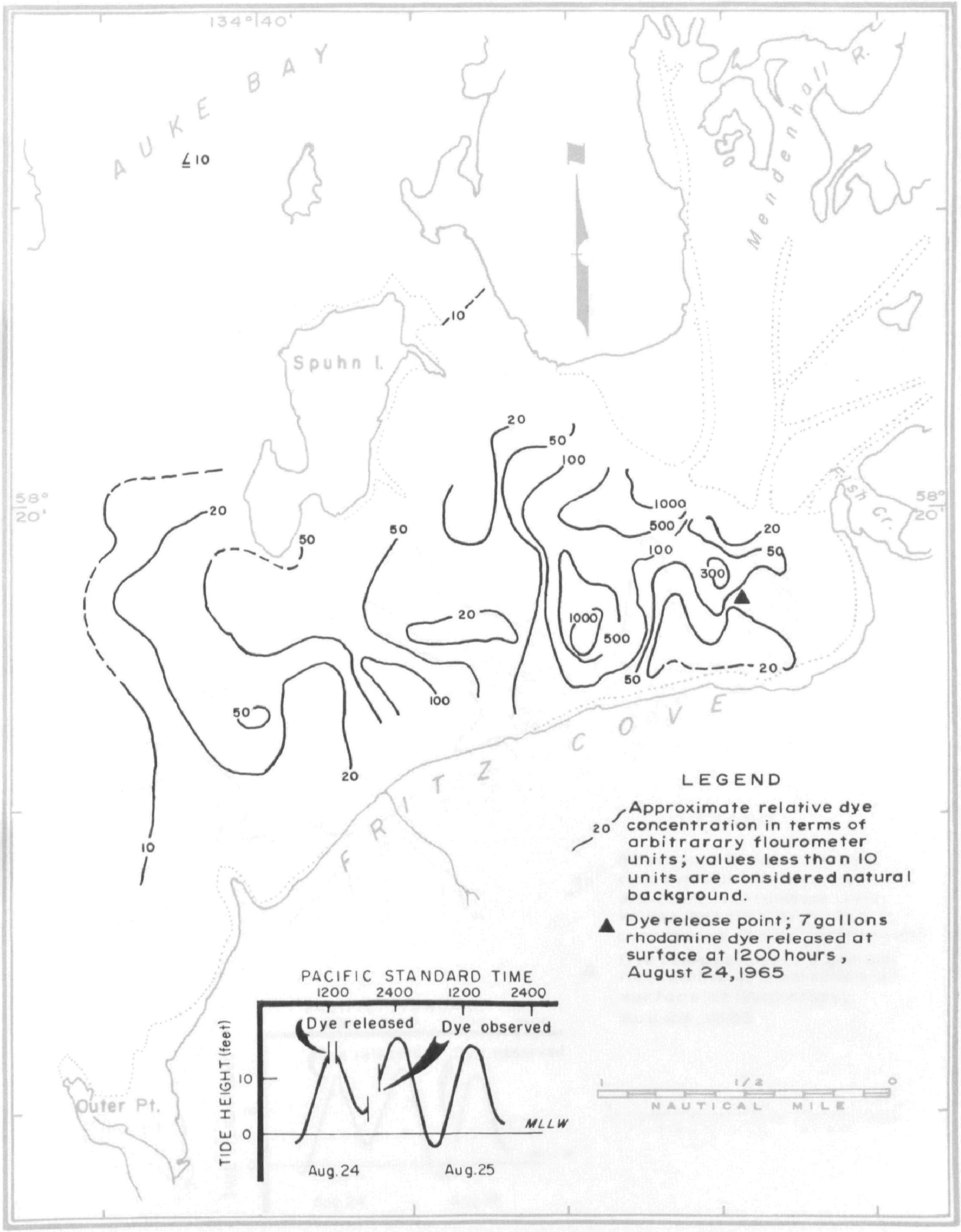

FIGURE 2-10. Surface dye dispersal pattern observed between 1930 and 2100 hours on August 24, following August 24 dye release.

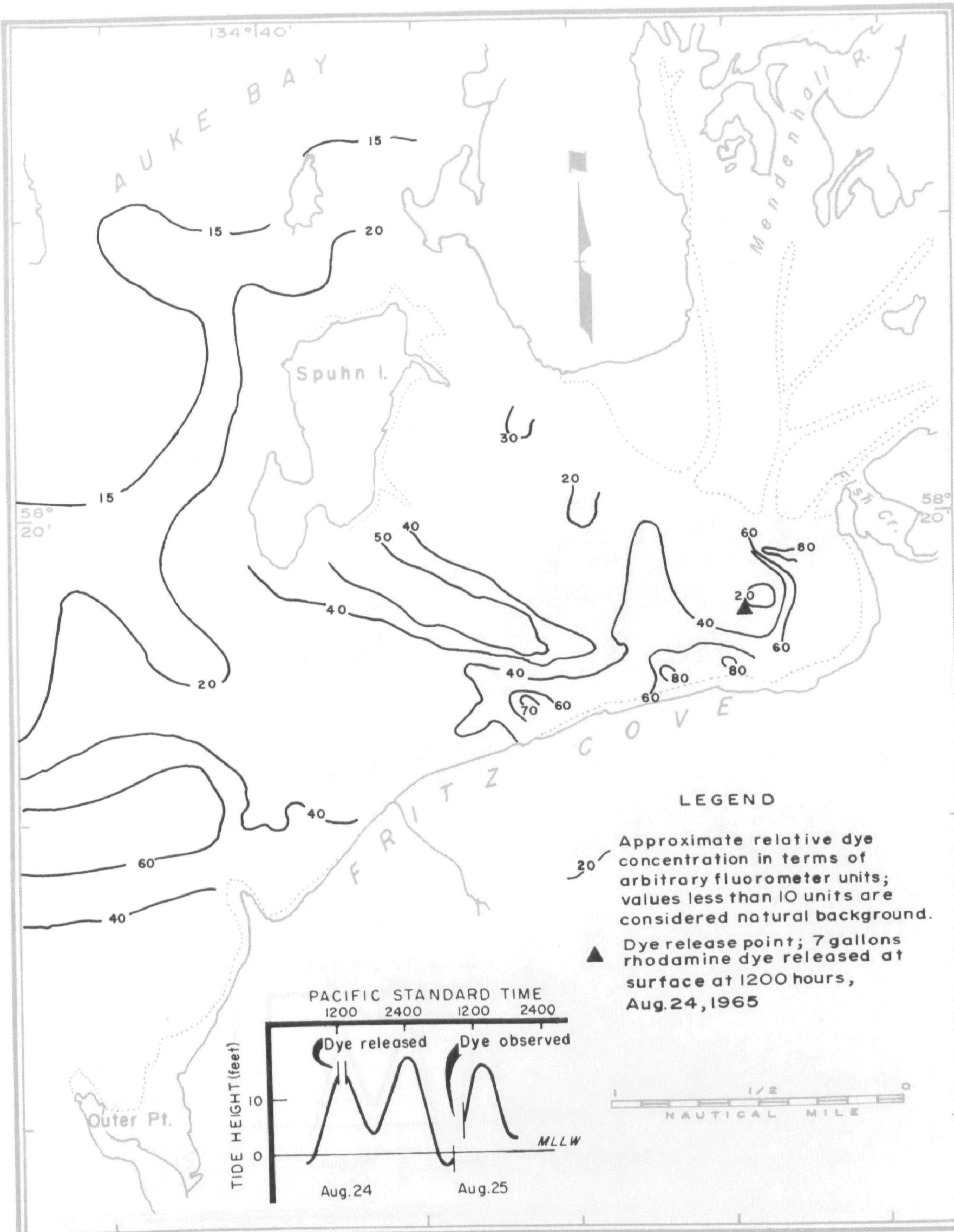

FIGURE 2-11. Surface dye dispersal pattern observed between 0830 and 0930 hours on August 25, following August 24 dye release.

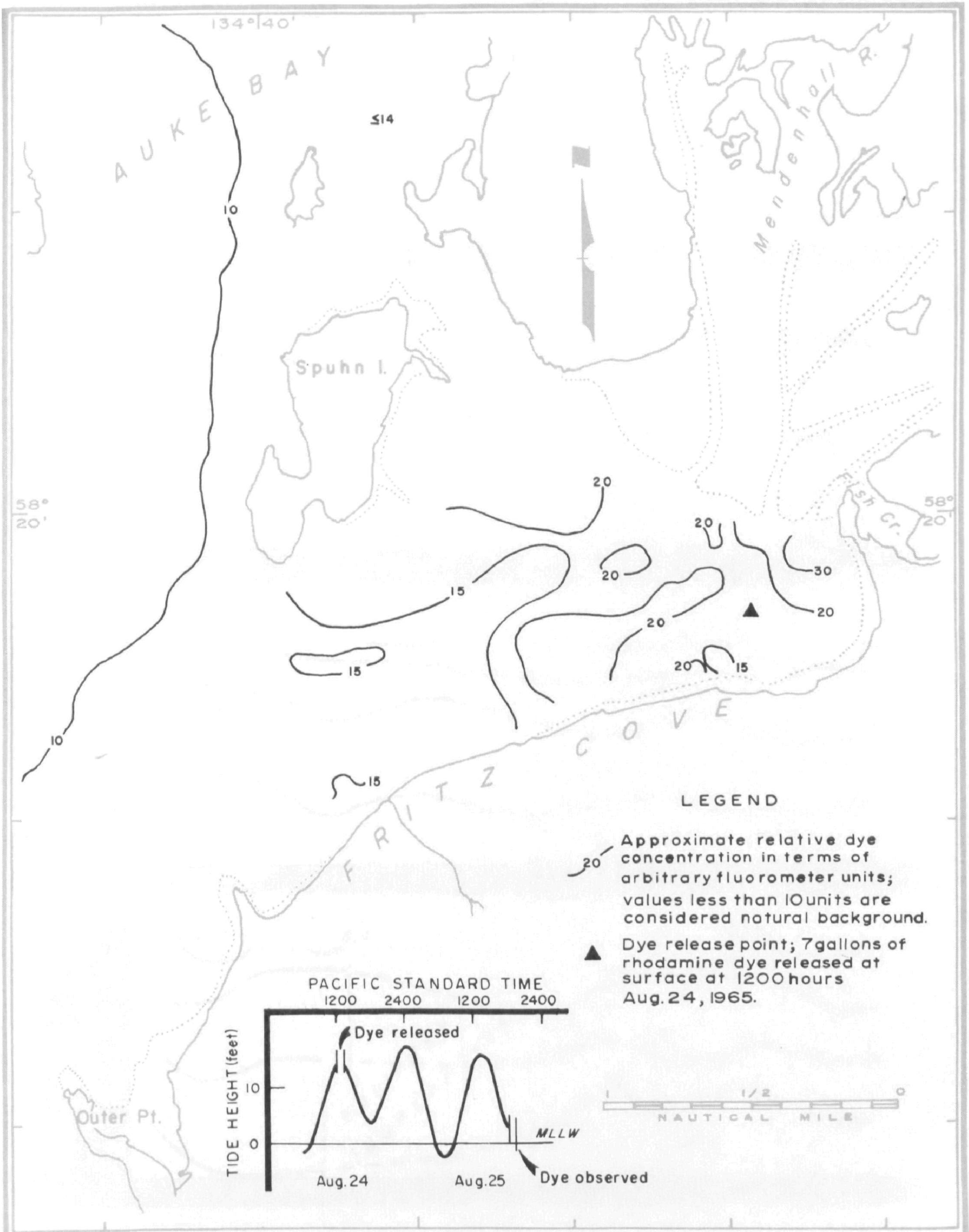

FIGURE 2-12. Surface dye dispersal pattern observed between 1830 and 1930 hours on August 25, following August 24 dye release.

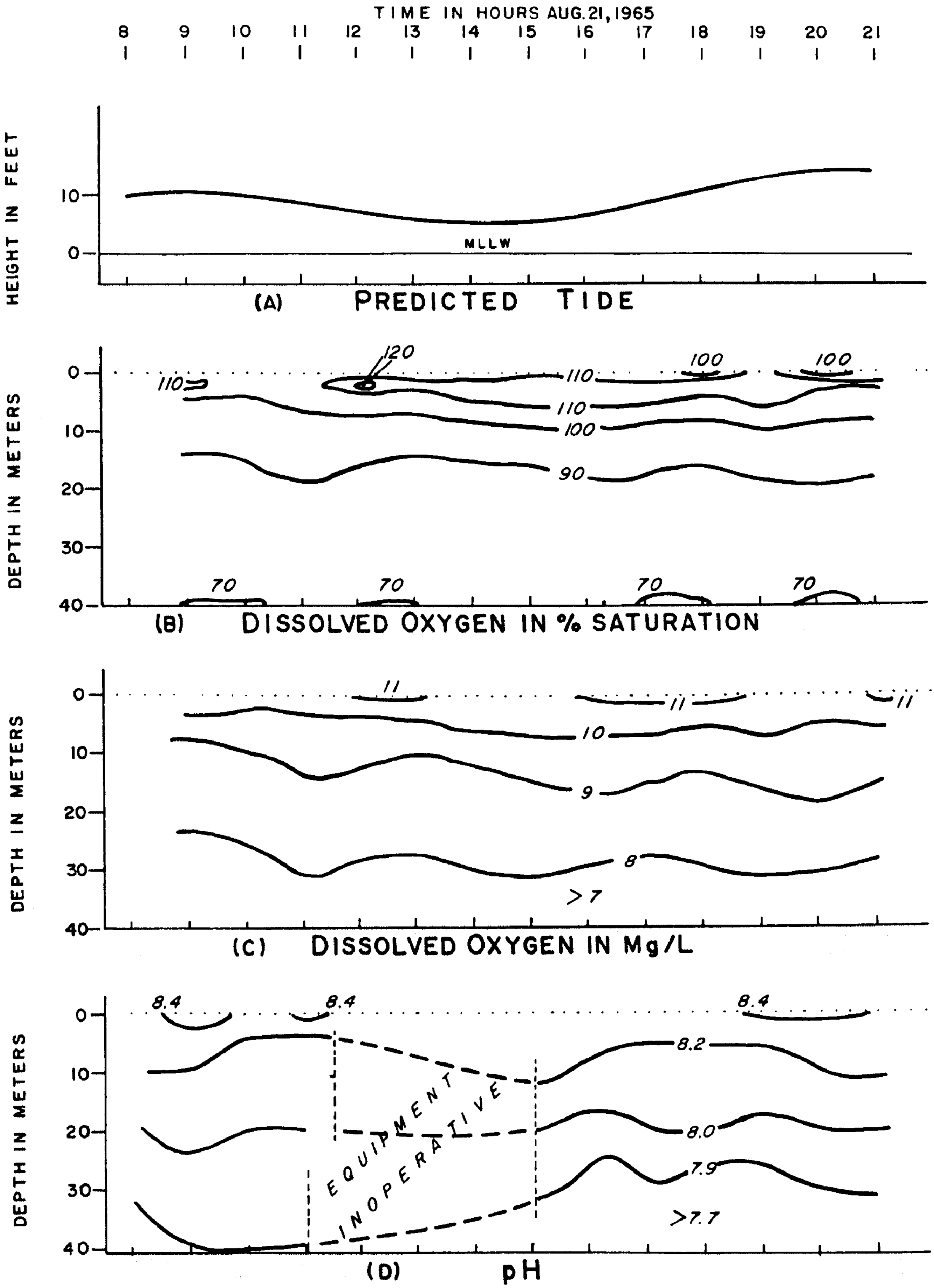

FIGURE 2-13. Patterns of (B) dissolved oxygen in percent saturation, (C) dissolved oxygen in milligrams per liter, and (D) pH at sampling Station A, August 21, 1965.

CHAPTER 3

SILVER BAY STUDY

August 26, 1965

STUDY OBJECTIVES

The August 26, 1965 water sampling survey conducted in Silver Bay was made to provide a preliminary evaluation of:

1. Distribution of wastes discharged from the Alaska Lumber and Pulp Co., Inc. sulfite mill located on Silver Bay.
2. Quality of the Bay waters, primarily in terms of dissolved oxygen and pH.
3. Water quality changes in Silver Bay resulting from pulp mill waste discharges.

BACKGROUND

The physical, chemical and biological characteristics of Silver Bay and approaches near Sitka, Alaska, were the subject of a comprehensive field survey in 1956-57 conducted jointly by Alaska Water Pollution Control Board and University of Washington, Department of Oceanography. The purpose of the survey was to establish existing environmental conditions and evaluate probable effects of waste discharge from a planned pulp mill to be located on Silver Bay (Figure 3-1)*. The study included evaluation of pulp mill wastes and processes, bioassays to determine biological effects of pulp mill wastes on marine life, and collection of data on the spatial and seasonal variations in the physical, chemical, and biological aspects of Silver Bay waters, shoreline, and bottom.

Alaska Water Pollution Control Board published the study results and recommendations in their Report No. 10, "Silver Bay Water Pollution Control Studies" (6). This report, referred to herein as Report No. 10, contains comprehensive descriptions of the area and its fisheries resources; pulping processes and waste characteristics; toxic effects of pulp mill wastes on marine life; pre-pollution evaluation of marine life and water quality in Silver Bay; physical characteristics of the Bay-area waters including currents, salinities, temperatures, and fresh-water inflow; and, based on the foregoing, recommendations concerning waste outfall location and the expected resulting waste distribution and water quality patterns in Silver Bay. In addition, Report No. 10

*Figures follow page 46

recommended a water quality surveillance program to be instituted following pulp mill construction.

Portions of Report No.10 will be referenced frequently in presenting and discussing results of the present survey.

The pulp mill, a magnesium-base sulfite process plant, was subsequently constructed at Sawmill Cove by the Alaska Lumber and Pulp Co., Inc. and discharges its wastes into surface waters of Silver Bay near Pt. Bucko (Figure 3-1). In keeping with recommendations of Report No. 10 for a surveillance program following pulp mill construction, the State of Alaska, Department of Public Health, requested this office to conduct the studies reported herein.

STUDIES

Water samples were collected on August 26, 1965 at thirteen stations located in Silver Bay (Figure 3-1). Station locations and numbering coincide with the thirteen principal sampling stations occupied during the 1956-57 pre-pollution studies. The sampling period in relation to predicted tide at Sitka is shown also on Figure 3-1.

Samples were collected from the surface and the 2, 5, 10, 20, 40, 60, and 80 meter depths, depth permitting, at each of the thirteen stations. Water characteristics determined for each depth were salinity, temperature, density, dissolved oxygen concentration, pH, and sulfite waste liquor (SWL) concentration. In addition, total water depth, surface water clarity, the continuous temperature-depth profile, and weather were observed for each station.

METHODS

All sampling was conducted from the 45-foot oceanographic research vessel, HAROLD W. STREETER. Station positioning of vessel was accomplished using sextant and radar navigation. Water samples at each station were collected simultaneously with 1.25-liter teflon-coated Nansen bottles. Each Nansen bottle sampler was equipped with a reversing thermometer which recorded *in situ* water temperature at the time of sampling. A bathythermograph attached to the lower end of the hydrographic wire was used to obtain a continuous record of the temperature-depth profile at each station.

Dissolved oxygen concentration, in terms of percent saturation, and pH were determined in the vessel laboratory immediately after sample retrieval. Analytical methods were essentially the same as those employed in the Gastineau Channel studies (see Chapter 1). A 400-ml portion of each sample was draughted and stored for subsequent salinity and SWL analyses at Washington Pollution Control Commission laboratory in Olympia, Washington, as follows:

Salinity -- Salinity in parts per thousand was determined using a Hytech, Model 6201, inductive salinometer.

SWL -- Sulfite waste liquor concentration in parts per million by volume was determined using the modified Pearl-Benson test (7). This test spectrophotometrically measures the lignin-sulfonate concentration of the sample relative to a laboratory reference solution of calcium-base, 10% dry solids by weight, sulfite waste liquor.

Surface water clarity was measured at each station using a 30-cm diameter, white Secchi disc suspended from a line graduated in meters. The Secchi-disc reading is a relative measure of turbidity and color and it represents the maximum depth to which the disc can be submerged before being obscured from surface view.

All station and sample data thus obtained were processed by electronic computer at University of Washington data processing center in Seattle, Washington. Processing provided calculation of water density and dissolved oxygen percent saturation, and data tabulation.

All data are on file at Federal Water Pollution Control Administration office, Portland, Oregon.

RESULTS

All data collected during the August 26, 1965 water sampling survey in Silver Bay have been reduced and tabulated according to station and depth, and are included in this report in the Appendix. Based on these data, vertical distributions of SWL, dissolved oxygen and pH for each of the thirteen sampling stations are presented on Figures 3-2 through 3-4.

PHYSICAL CONDITIONS DURING SAMPLING PERIOD

Physical conditions in Silver Bay--density stratification, tides, wind, weather--will affect the distribution of pulp mill wastes and the resulting water quality. Weather conditions on August 26, 1965 were mild, with light and variable westerly winds less than 10 knots, overcast skies and intermittent rain. Based on official marine radio weather reports monitored each day by the HAROLD W. STREETER, weather throughout this area was very mild for the several days preceding sampling. Water sampling was conducted during the first part of the ebb tide (Figure 3-1).

Specific data were not obtained for freshwater inflow to Silver Bay during the survey period. However, the summer season is normally a period of higher runoff for the area (see Report No. 10) and freshwater inflows were probably above average during the August 26 survey. Near-surface salinities within Silver Bay were lower than those at the entrance, thus indicating a significant amount of freshwater inflow to the Bay. Based on data in the Appendix, vertical distributions of salinity and density (in terms of specific gravity) are shown on Figure 3-5 for a mid-bay transect extending through Stations 1, 3, 6, 11, and 13. This figure illustrates the shallow layer of lower salinity, lighter density water at the surface resulting from freshwater inflow. The stability of this layer, due to its relatively lighter density, inhibits vertical mixing of the surface waters (and wastes discharged to surface waters) into the deeper Bay waters.

WASTE DISTRIBUTION

Distribution of pulp mill wastes, as described by SWL concentrations, was widespread in the surface waters of Silver Bay and approaches. Examination of the station curves (Figures 3-2 through 3-4), the Appendix, and the salinity-density transect (Figure 3-5) indicates:

1. Wastes are confined to the low-density near-surface layer.
2. Maximum SWL value at each station is at the surface.
3. SWL concentration decreases rapidly with depth at all stations. Virtually all SWL is situated within 10 meters of the surface, and most of it is above the 2 meter depth.

Horizontal distributions of SWL in Silver Bay at the surface and the 2 and 5 meter depths are shown on Figures 3-6 through 3-8. Surface SWL concentrations vary from a maximum of 3,220 ppm near the waste outfall at Pt. Bucko to 71 ppm at Station 11. There is no strong one-way dispersal pattern away from the source which might be related to a dominant net transport process, *e.g.*, strong net outflow of fresher surface water. Rather, surface SWL distribution is characterized by its widespread uniformity of high concentrations, generally above 200 ppm, throughout the Silver Bay area. This indicates a slow flushing process with dispersal dominated by tidal action.

WATER QUALITY

Dissolved Oxygen. Based on dissolved oxygen values illustrated on the station curves (Figures 3-2 through 3-4) and listed in the Appendix, vertical distribution of dissolved oxygen concentration at each of the thirteen sampling stations in Silver Bay is characterized by:

1. Low surface DO concentration; surface values ranged between 49% and 71% saturation (4.4-7.1 mg/l).
2. Rapid increase in DO concentration with depth, from a low surface value, to a maximum value at a depth between 2 and 10 meters; maximum values ranged from 79% to 90% saturation (7.2-8.0 mg/l).
3. Gradual decrease in DO concentration with depth below the depth of maximum concentration; for stations sampled at the 60 meter depth, concentrations ranged from 40% to 62% saturation (3.9-5.8 mg/l).

Depth of the oxygen-depressed surface layer coincides with the depth of the waste-confining, low-density layer of fresher surface waters.

Horizontal distribution of dissolved oxygen concentration at the surface and 2 meter depth is shown on Figures 3-9 and 3-10, respectively. In general, surface DO concentration is 2-3 mg/l less than that at the 2 meter depth. As with the SWL distributions (Figures 3-6 through 3-8) horizontal distribution of dissolved oxygen at a given depth is quite uniform throughout the Bay area. The isolated, slightly higher surface-DO value observed at Station 9 (Figure 3-9) is probably associated with freshwater discharge from Sawmill Creek, as evidenced by the correspondingly low surface salinity measured at this station (see Appendix).

pH. Vertical distribution of pH at each station (Figures 3-2 through 3-4) is similar to that for dissolved oxygen; *i.e.*, low surface value, rapid increase with depth below the surface to a maximum value at a depth between 2 and 10 meters, and gradual decrease with depth below the depth of maximum pH. Surface pH values varied between 7.05-7.65 while those at the 2 meter depth varied between 7.88 and 8.08. Near-surface lowering of pH occurs in the low-density surface waters.

Secchi disc. Secchi-disc measurements, shown for all stations on Figure 3-11, varied from 1.3 to 8.3 meters. Lowest Secchi-disc readings, *i.e.*, least transparent waters, were found nearest the pulp mill where highly colored wastes are discharged. Surface waters throughout Silver Bay and approaches were observed to have a blackish cast. In lowering the Secchi disc into the water, the disc was usually observed to nearly disappear within the first one or two meters of submergence, then continue to be only faintly visible for another several meters. This pattern reflects confinement of wastes within the low-density surface layer.

DISCUSSION

Water quality patterns observed in Silver Bay on August 26, 1965 were considerably different than any monitored during the 1956-57 pre-pollution studies, particularly in the waste-confining surface waters. However, because of the many natural processes which variably effect DO, pH, water clarity, etc., a specific portion of the observed change cannot be attributed solely to the presence of pulp mill wastes on the basis of a single cruise.

In the discussion that follows, SWL and DO values measured on August 26, 1965 are compared with predicted values outlined in Report No. 10. In addition, certain apparent effects of pulp mill wastes on the water quality parameters are described as based on the present sampling survey.

WASTE DISTRIBUTION

The SWL distribution observed during the August 26 survey did not closely resemble any of the three patterns predicted in Report No. 10. The primary differences arise from the basic assumptions for prediction; (a) that wastes would be uniformly mixed to a depth of 16 feet (about 5 meters), and (b) that transport and dispersal from the source would be either eastward into the Bay or westward out of the Bay, depending on the combination of wind, tide, and runoff. Waste distribution observed on August 26 was not vertically well mixed and did not exhibit a strong one-way pattern of dispersal away from the source. Depth-averaging of observed values to a depth of 5 meters would result in values less than one-third of those observed at the surface. Such depth-averaged values generally would fall within maximum values predicted at any point (Report No. 10).

It is important to note that wastes are not well mixed and, as a result, extremely high SWL values occur in surface waters throughout the Silver Bay area (Figure 3-6). According to bioassay studies presented in Report No. 10, these observed SWL levels would be more than sufficient to cause some kill of important food chain organisms such as copepods, enphausids, mysids, and candlefish. Conditions prevailing during the August 26 survey were not particularly conducive to detention of wastes in Silver Bay, and it is expected that even higher surface SWL concentrations would result during periods of persistent strong southerly or westerly winds. An increase of SWL concentration to 500-600 ppm would result in death of herring and fingerling salmon (Report No. 10). Furthermore, recent bioassay studies conducted by this office to determine effects of pulp mill wastes on oyster larvae and bottom-fish eggs show that these immature life-stages incur severe developmental abnormalities and mortalities at SWL levels well below those observed in Silver Bay during the August 26 survey.

WATER QUALITY

Dissolved Oxygen. Distribution of DO in Silver Bay during the August 26 survey (Figures 3-9 and 3-10) also differed from those patterns predicted in Report No. 10, primarily in the same respects as mentioned for the SWL distribution; *i.e.*, the presence of vertical concentration gradient near the surface and lack of a strong one-way dispersal of wastes away from the source. The predicted DO values (Report No. 10) represent the minimum expected DO values corresponding to predicted SWL patterns. Depth-averaging of observed DO values to a depth of 5 meters (16 feet), to compare with predicted values, would result in average DO concentrations of about 6.5-7.5 mg/l, which is slightly greater than the predicted minimum values.

Based on the 1956-57 pre-pollution surveys, the summer dissolved oxygen profile in Silver Bay, in the absence of pulp mill wastes, was typified by lowest concentration near the bottom, but not less than 6 mg/l, followed by a gradual concentration increase toward the surface to maximum values of at least 9 mg/l. Also, near-surface waters were normally supersaturated with dissolved oxygen to at least 5 meters depth. This increase in DO toward the surface is partially associated with primary plankton productivity in the presence of sunlight. DO profiles measured in Silver Bay on August 26 (Figures 3-2 through 3-4), however, show two significant departures from pre-pollution profiles:

1. DO concentrations below the 60 meter depth throughout the study area were less than 6 mg/l and, at Stations 2, 7, and 12, were less than 4 mg/l.
2. Maximum DO values of about 7 to 8 mg/l (90% saturation or less) occurred at 2 to 10 meters depth, with a subsequent rapid decrease toward the surface to low surface values generally between 4 and 6 mg/l.

It is pointed out in Report No. 10 that any decrease in near-bottom DO to less than 5 mg/l, over a protracted period (3 or 4 months), would be evidence of decomposition over and above that found naturally in the Bay. However, up-welled oxygen-deficient ocean water is normally present at depth by late summer in many of the coastal bays and inlets along the north Pacific coast. On August 26, DO values less than 5 mg/l occurred at depths below 60 meters at the entrance to Silver Bay (Station 1) in the absence of any detectable SWL while, at any given depth below 40 meters, DO values within the Bay were generally less than at the entrance. This suggests that both up-welling and oxygen utilization in the Bay are responsible for the observed extreme oxygen deficit at depth.

Examination of the station curves (Figures 3-2 through 3-4) and the data tabulation in the Appendix shows that the near-surface decrease in dissolved oxygen is limited to the waste-confining, low-density surface layer. In this layer, dissolved oxygen concentration consistently decreases as the SWL concentration increases. This mirror-image effect is noticeable in areas of Puget Sound, Washington, where pulp mill wastes also are discharged into estuarine waters. The near-surface oxygen deficit is attributed to both biochemical oxygen demand of the pulp mill wastes and to a possible reduction in phytoplankton oxygen production because of the inhibiting effects of strong wastes.

The gradual decrease in dissolved oxygen concentration with depth in the deeper waters is natural but, although decomposition at depth within the Bay may contribute to this decrease, a specific portion of the deficit cannot be assigned either to natural causes or to waste decomposition on the basis of a single cruise. On the other hand, no significant near-surface decrease in DO was observed at any time during the pre-pollution study; therefore, that observed on August 26 is considered primarily the result of the oxygen demand of pulp mill waste discharge into Silver Bay. The observed surface DO values throughtout the area (Figure 3-9) are borderline to the generally recommended minimum value of 5 mg/l necessary for marine life and are less than the 6 mg/l recommended in Report No. 10 as desirable to maintain the fishery at its full potential. In view of the season, weather conditions, and evident oxygen resource beneath the waste layer, conditions prevailing during the August 26 survey cannot be considered the most critical likely to be encountered. Any reduction of dissolved oxygen beyond that observed on August 26 in the surface waters of Silver Bay will definitely place the values below recommended minimum levels.

<u>pH</u>. The pH measured in Silver Bay during pre-pollution studies varied between 7.2 and 8.4 and, at any given station, generally increased from a low value at depth to a maximum near the surface. Such a vertical trend is normal in coastal waters during the summer and is associated with a relative decrease in dissolved CO_2 toward the surface. The CO_2 gradient, in turn, is affected by photosynthetic activity (decreased CO_2, increased pH), biorespiration and decomposition (increased CO_2, decreased pH) and dilution by local runoff (generally lower pH). The pH measured during the August 26, 1965 sampling survey varied from 7.05 to 8.08 and, at each station, increased gradually from a low value at the bottom to a maximum value at 2-10 meters depth, then rapidly decreased to a low surface value. The near-surface decrease in pH

occurred in the waste-confining, low-density surface waters. No similar near-surface pH decrease in the presence of low surface salinities was observed during pre-pollution studies and, for this reason, the lowering of surface pH observed throughout Silver Bay on August 26 cannot be solely attributed to simple dilution by local runoff. In view of the waste distribution and dissolved oxygen profile at each station (Figures 3-2 through 3-4), much of the near-surface decrease in pH appears to be the combined result of biochemical waste decomposition, acid nature of the pulp mill wastes, and reduced photosynthetic production in the waste layer.

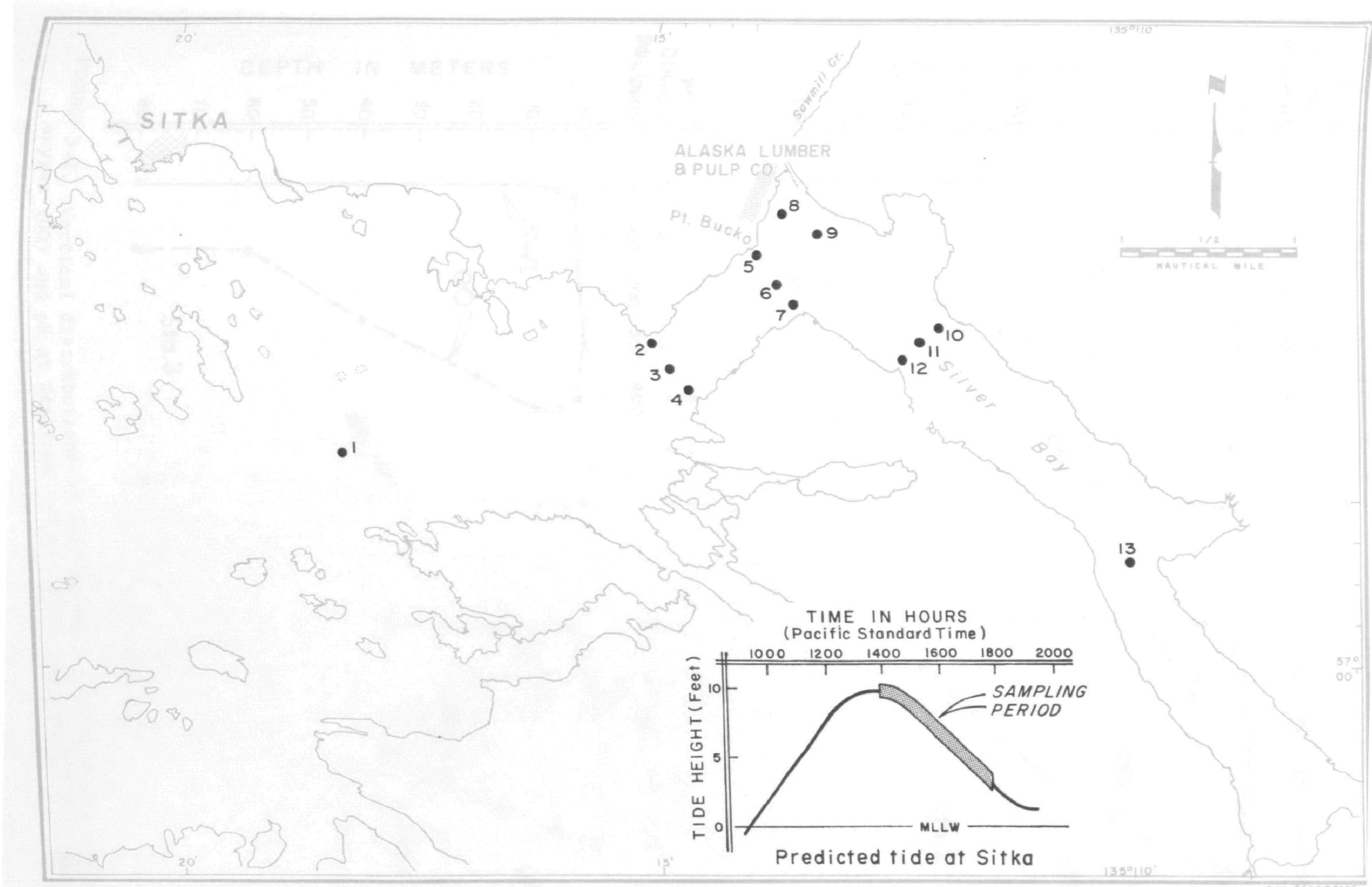

FIGURE 3-1. Silver Bay study area, sampling locations, and sampling period, August 26, 1965.

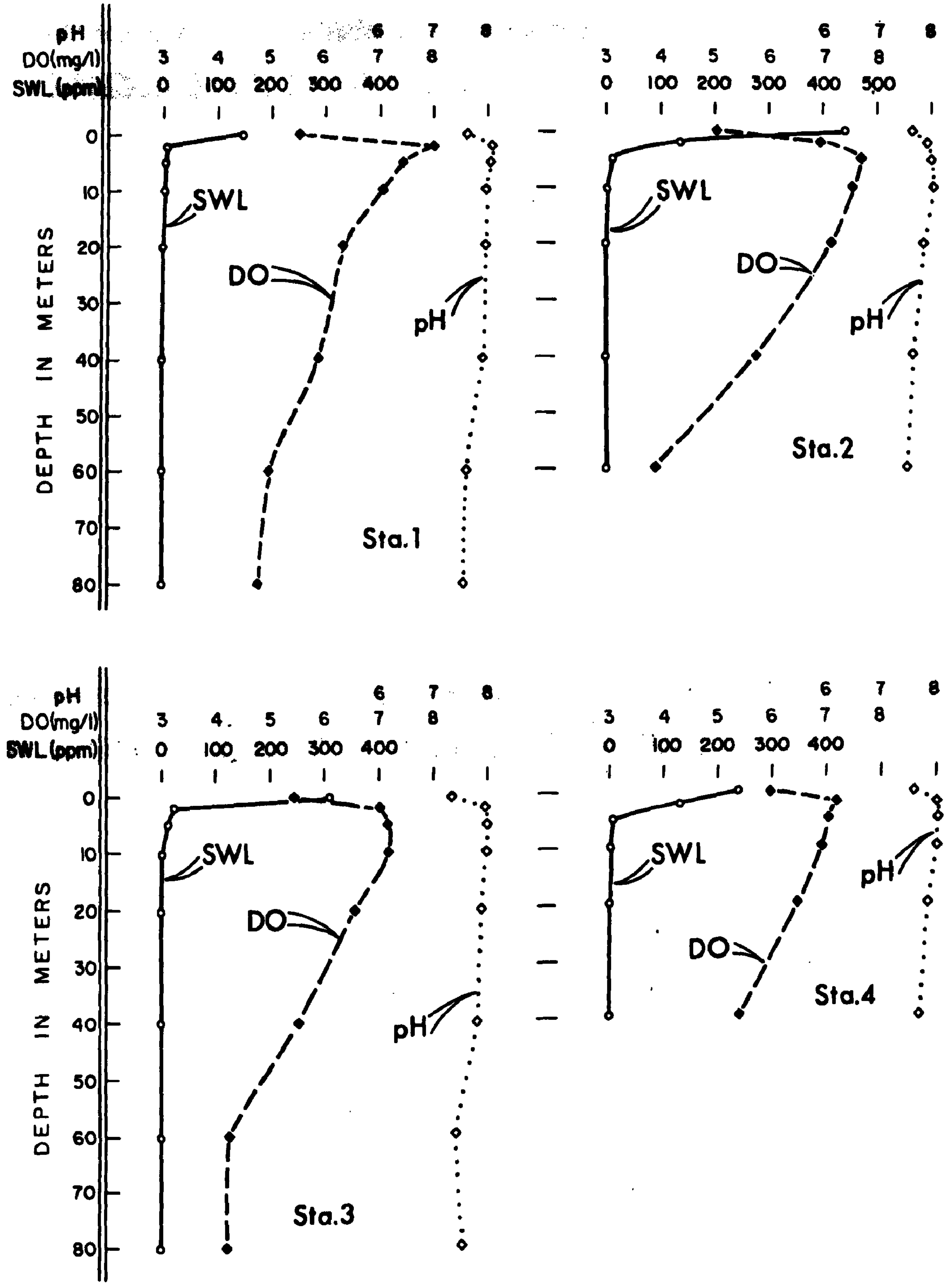

FIGURE 3-2. Vertical distributions of sulfite waste liquor (SWL), dissolved oxygen (DO) and pH at Stations 1-4 in Silver Bay; August 26, 1965.

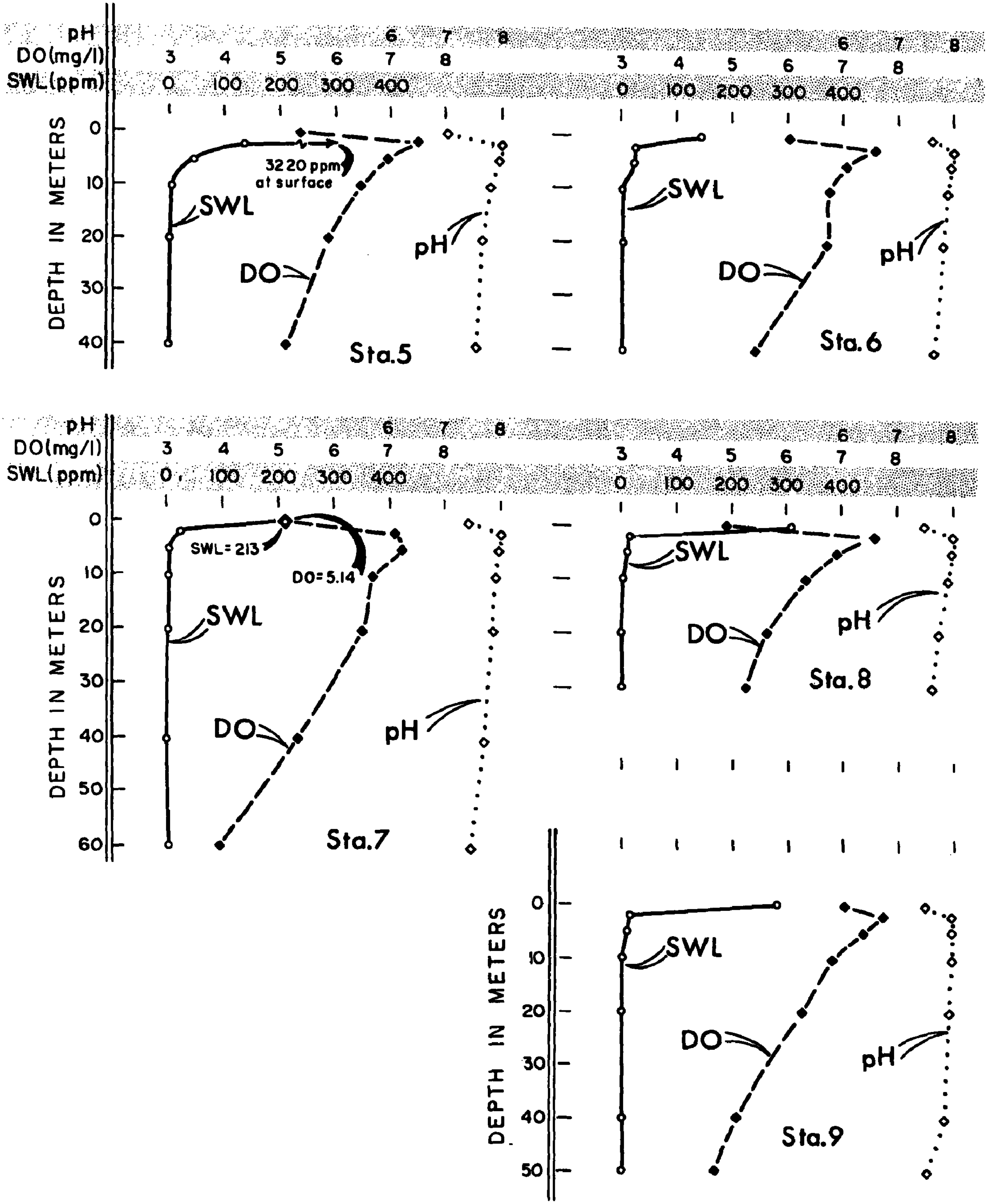

FIGURE 3-3. Vertical distributions of sulfite waste liquor (SWL), dissolved oxygen (DO), and pH at Stations 5-9 in Silver Bay; August 26, 1965.

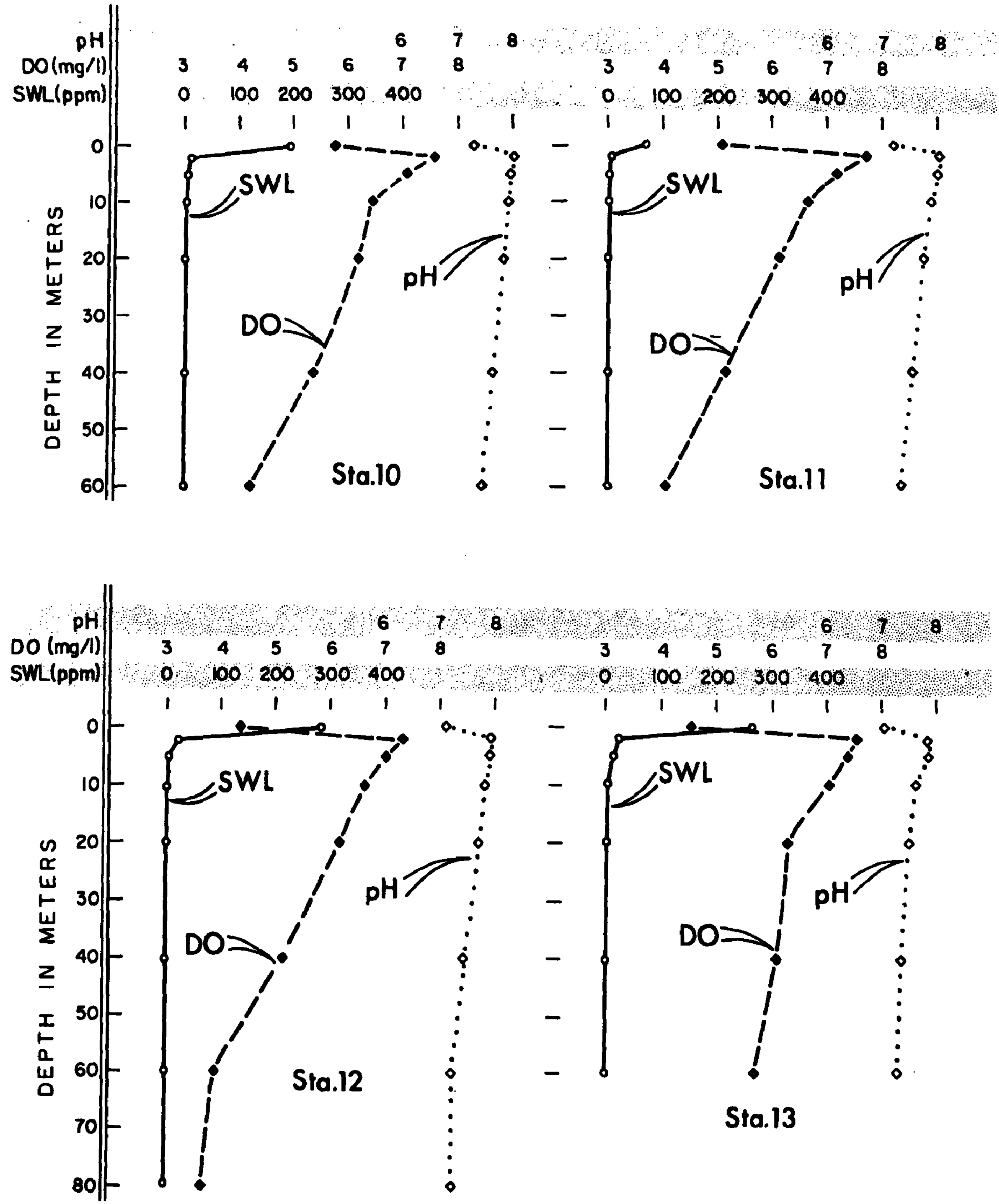

FIGURE 3-4. Vertical distributions of sulfite waste liquor (SWL), dissolved oxygen (DO) and pH at Stations 10-13 in Silver Bay; August 26, 1965.

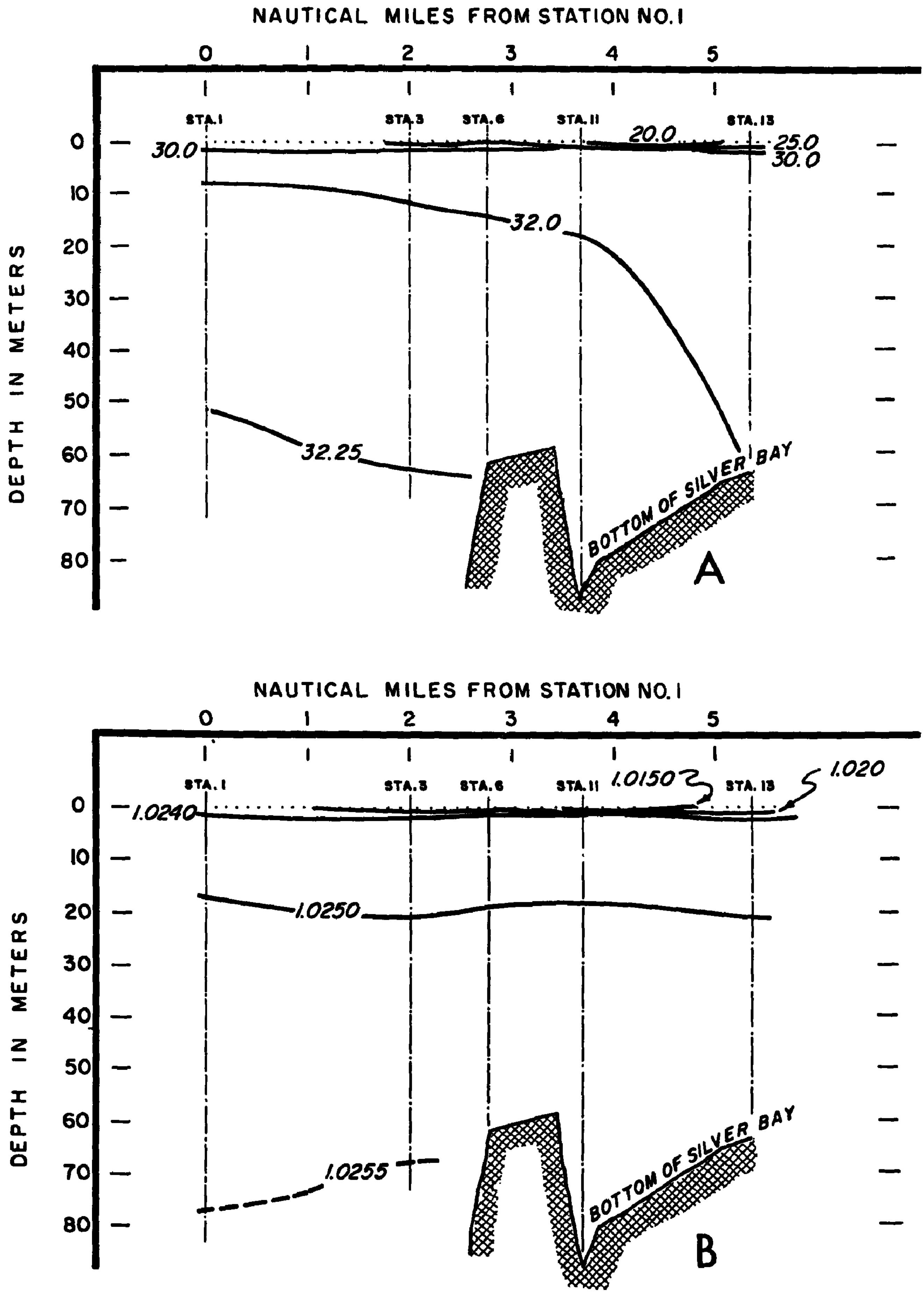

FIGURE 3-5. Vertical patterns of (A) salinity and (B) density (in terms of specific gravity) along a mid-bay transect in Silver Bay; August 26, 1965.

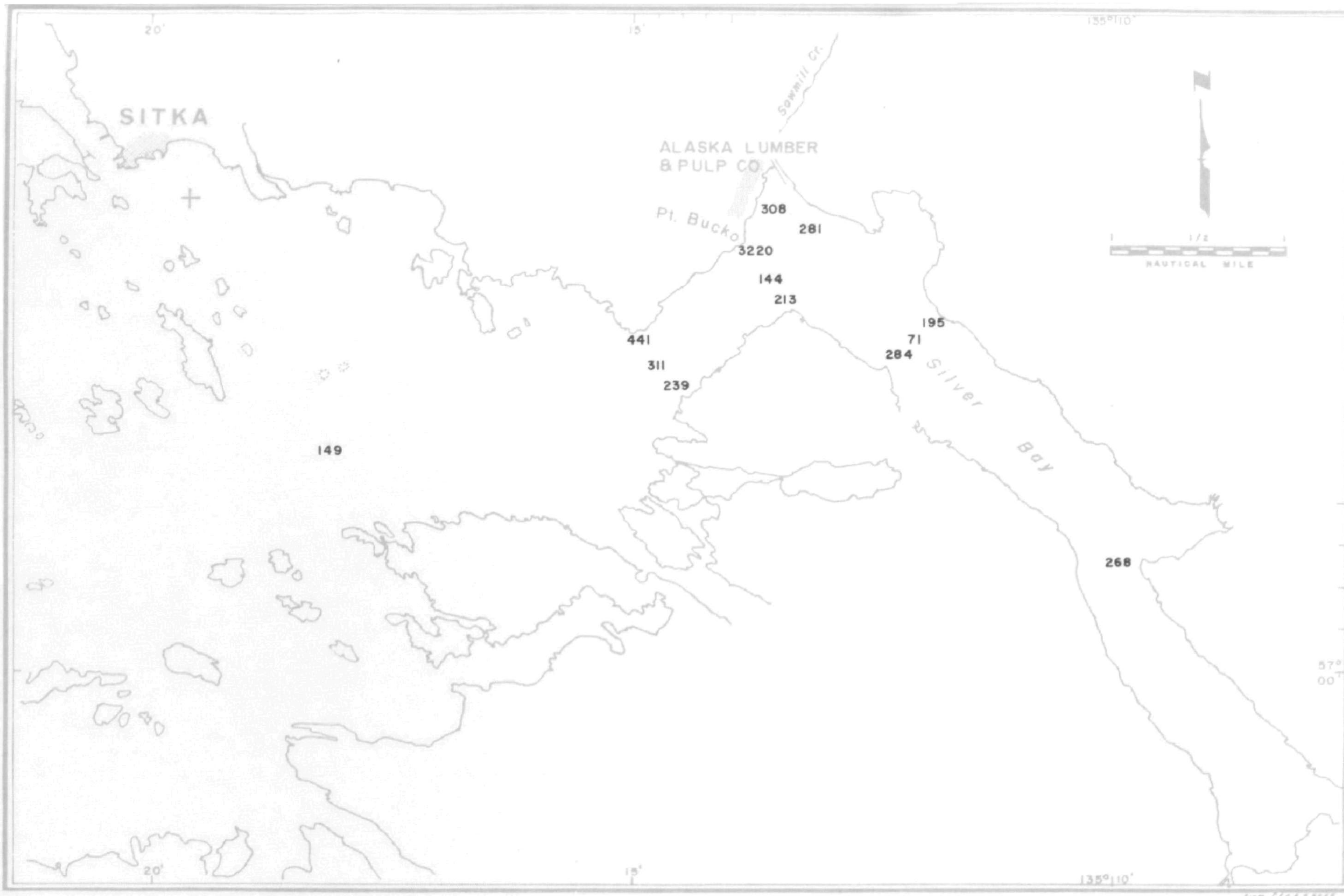

FIGURE 3-6. Surface concentrations (ppm) of sulfite waste liquor in Silver Bay; August 26, 1965.

FIGURE 3-7. Concentrations (ppm) of sulfite waste liquor at 2 meters depth in Silver Bay; August 26, 1965.

FIGURE 3-8. Concentrations (ppm) of sulfite waste liquor at 5 meters depth in Silver Bay; August 26, 1965.

FIGURE 3-9. Surface concentrations (mg/1) of dissolved oxygen in Silver Bay; August 26, 1965.

FIGURE 3-10. Concentrations (mg/l) of dissolved oxygen at 2 meters depth in Silver Bay; August 26, 1965.

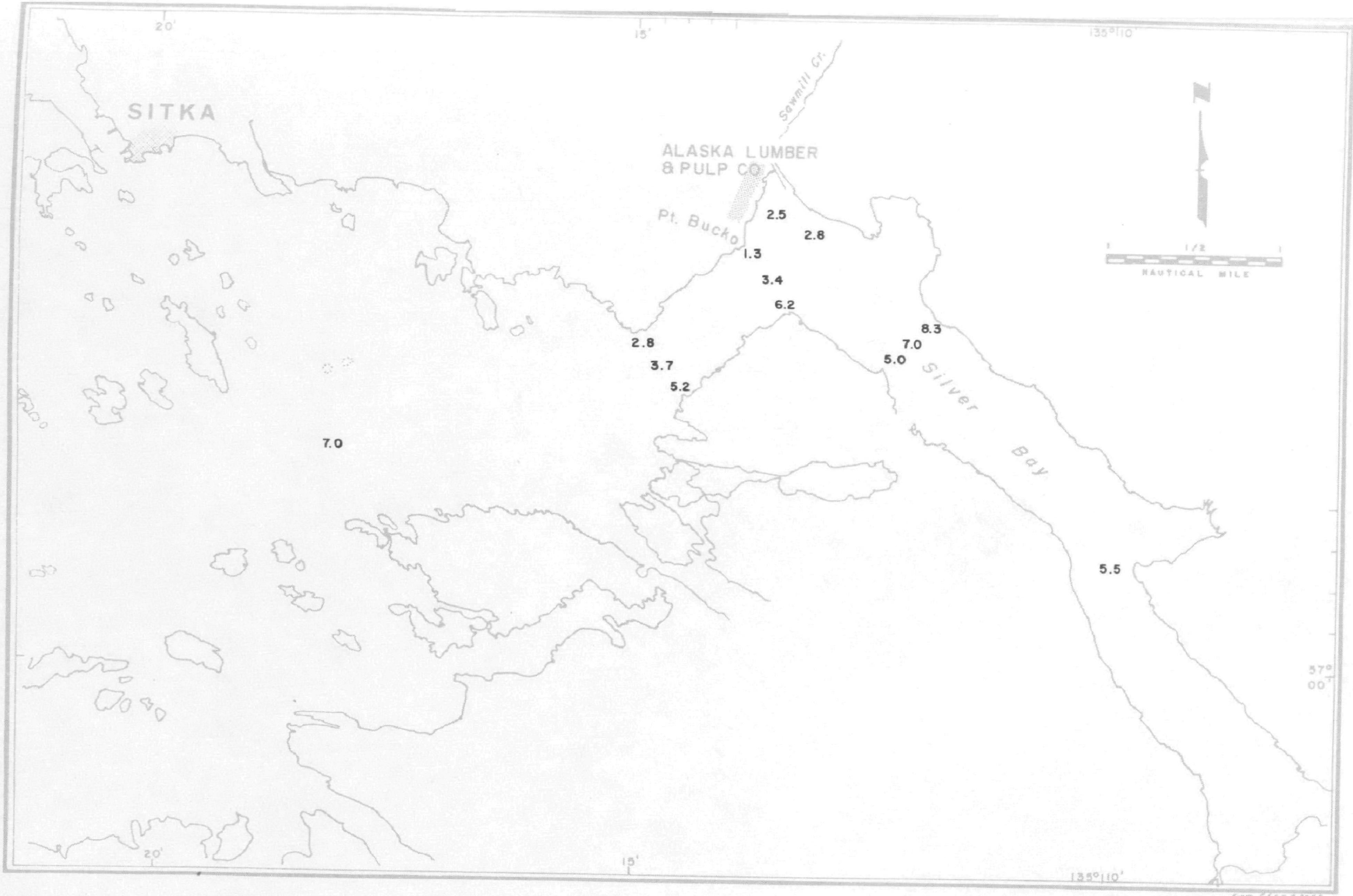

FIGURE 3-11. Secchi-disc measurements (meters) in Silver Bay; August 26, 1965.

CHAPTER 4

WARD COVE STUDY

August 28, 1965

STUDY OBJECTIVES

The August 28, 1965 water sampling survey conducted in Ward Cove and adjacent waters of Tongass Narrows was made to provide a preliminary evaluation of:

1. Distribution of wastes from the Ketchikan Pulp Company pulp mill located on Ward Cove.
2. Quality of the waste-receiving waters, primarily in terms of dissolved oxygen and pH.
3. Water quality changes in Ward Cove resulting from pulp mill waste discharges.

BACKGROUND

A comprehensive study of Ward Cove area waters, near Ketchikan, Alaska, was conducted over a one-year period in 1951-52 by the Alaska Water Pollution Control Board. Purpose of the study was to describe chemical, biological, physical, and hydrologic characteristics of Cove waters prior to construction of a proposed pulp mill to be located on Ward Cove (Figure 4-1)*.

Study results were summarized in Alaska Water Pollution Control Board Report No. 7, "Ward Cove Survey, Ketchikan, Alaska" (8). This report, referred to herein as Report No. 7, presents brief descriptions of the area and its water resources; the annual cycles of dissolved oxygen concentration and water temperature at selected depths; the annual cycles of depth-averaged BOD, chlorides, total solids, and turbidity; ranges and variations of pH, alkalinity, calcium, sulphates, magnesium, and color; the biological inhabitants of the area waters, bottom, and shoreline, including the annual cycles of diatoms, copepods, bottom specimens, and coliform density; and hydrologic data including freshwater inflow and tidal currents.

Portions of Report No. 7 will be referenced frequently in presenting and discussing results of the present survey.

Ketchikan Pulp Company, Ketchikan, Alaska, constructed a pulp mill on Ward Cove in 1954 and since that time has discharged its wastes into Cove surface waters (Figure 4-2). In order to evaluate the present condition of Cove waters under this waste loading, the State of Alaska,

*Figures follow page 61

Department of Public Health, asked the assistance of this office in observing waste distribution and water quality in the Ward Cove area.

DESCRIPTION OF THE WASTE SOURCE

The Ketchikan Pulp Company mill operated on Ward Cove is a magnesium-base, sulfite process pulp mill. Production of dissolving grade pulp is normally about 580 tons/day. Usual recovery operations are employed to collect, evaporate, and burn the pulping liquor for recovery of magnesium oxide and return of chemicals to the pulping cycle.

During the period October 21-24, 1963 this office, in cooperation with mill management and the Department of Health and Welfare, State of Alaska, conducted a three-day in-plant survey of mill wastes discharged from separate unit processes, and as discharged to Ward Cove. The several in-plant waste streams measured and sampled provided information concerning waste loads from separate steps in the process. All wastes from the mill combine to discharge to Ward Cove through two outfalls which were sampled and measured to obtain data regarding total plant loading to the waterway. Samples were transported by air-freight for analysis by the Columbia Basin Project Laboratory of the U. S. Public Health Service in Portland.

Mill management provided complete information concerning waste flow and production values. These data, coupled with the analytical information obtained, permitted calculation of mill losses and waste loadings to the waterway. Consideration of the values obtained results in several general conclusions concerning mill wastes discharged over the survey period as follows:

1. The pounds of BOD_5 discharged per ton of production was about 300 pounds on a two-day average with normal recovery operations. This discharge level represents a 70% reduction in oxygen demand loading as compared to BOD_5 values discharged by other Pacific Northwest mills producing similar products but without recovery and re-cycle of chemicals.

2. Discharge of sulfite waste liquor solids, as determined by the Pearl-Benson test, was about 1,100 tons per day or about 3,500 pounds per ton of product. These values indicate a reduction of about 90% in materials reactive to this measurement as compared with sulfite mills without recovery processes.

3. Volatile suspended solids losses were higher than desirable. The average loss of 88 pounds per ton of product representing 27.7 tons of volatile suspended solids per day was higher than expected. Volatile suspended solids losses ranged from 4.2% to 4.5% of production.

Mill wastes are discharged into Ward Cove via two outfalls: the main sewer, located as shown on Figure 4-2, which discharges about 95% of the BOD and SWL loadings and over 80% of the volatile suspended solids; and the woodroom sewer, which handles the remainder of the wastes, derived mainly from barking operations and magnesium-oxide recovery process. Based on the in-plant survey, main sewer discharge averaged 34.4 mgd (about 53 cfs) with the following waste concentrations:

5-day BOD	610 mg/l
COD (chemical oxygen demand)	1,940 mg/l
Sulfite waste liquor 1/	7,285 mg/l
Suspended volatile solids	160 mg/l

1/ Pearl-Benson Index (PBI), calculated on a 10% solids basis. (see Chapter 3, Page 37 for definition)

Mill production during the period of survey averaged 628 tons per day, somewhat in excess of the designed rate of 580 tons/day. For this reason mill losses measured may not be truly typical of a mill operating at design production levels.

STUDIES

Water samples were collected on August 28, 1965, at thirteen stations located in Ward Cove and Tongass Narrows (Figure 4-2). The sampling period in relation to predicted tide at Ketchikan also is shown on this figure.

Samples were collected from the surface and the 2, 5, 10, 20, 40, and 60 meter depths, depth permitting, at most of the thirteen stations, with some minor variation necessitated by limiting depth.

METHODS

Sampling and analytical methods used during the Ward Cove survey were essentially the same as those used in the previously described Silver Bay study (see Chapter 3).

All data is on file at Federal Water Pollution Control Administration office, Portland, Oregon.

RESULTS

All data collected during the August 28, 1965 water sampling survey in the Ward Cove area have been reduced and tabulated according to station and depth, and are included in the Appendix of this report. Based on these data, vertical distributions of SWL, dissolved oxygen and pH for each of the thirteen sampling stations are shown on Figures 4-3 and 4-4.

PHYSICAL CONDITIONS DURING SAMPLING PERIOD.

Weather conditions on August 28, 1965 were mild, with light and variable westerly winds less than 9 knots, mostly clear skies and sunshine. Marine radio weather reports monitored each day aboard the HAROLD W. STREETER indicated the weather had been mild for several days preceding sampling.

Samples were collected over a three-hour period beginning near the time of predicted low tide at Ketchikan (Figure 4-2).

Data concerning freshwater inflow to Ward Cove were not obtained for the survey. Based on hydrologic information in Report No. 7, local inflow is primarily from rainfall and, in view of the season and mild weather, was probably below average during the August 28 study. Examination of the salinity and density (sigma-t) data in the Appendix shows:

1. Waters in Tongass Narrows and Ward Cove were stably stratified, *i.e.*, density increases significantly with depth at all

stations, thus inhibiting downward mixing of surface-discharged wastes.

2. Near-surface salinity within the Cove is generally less than that in Tongass Narrows. This indicates at least some local freshwater inflow to the Cove with a consequent net outflow in the surface waters.

WASTE DISTRIBUTION

Pulp mill waste, described in terms of SWL, was found in varying concentrations at all stations sampled (Figures 4-3 and 4-4 and tabulated data in the Appendix). At each station, maximum SWL value occurred at or near the surface and ranged from 24 ppm at Station 4 in Tongass Narrows to 989 ppm at Station 6 in Ward Cove. SWL concentration decreased rapidly with depth at each station to minimum values of essentially zero (background in the absence of pulp mill waste) at depths below 20 meters.

Surface SWL values ranged from 24-41 ppm in Tongass Narrows and from 485-989 ppm in Ward Cove (Figure 4-5). There was no apparent strong path of waste movement away from the mill in Ward Cove or away from Ward Cove in Tongass Narrows.

WATER QUALITY

Dissolved Oxygen. Vertical distribution of dissolved oxygen at each station (Figures 4-3 and 4-4 and tabulated data in the Appendix) is characterized by:

1. A maximum dissolved oxygen concentration located between 5 and 10 meters depth. Maximum values varied from 7.33 mg/l

(85% saturation) in Tongass Narrows to 5.59 mg/l (64% saturation) in Ward Cove.

2. Decrease in DO toward the surface from the depth of maximum value. Surface values ranged between 6.41 mg/l (75% saturation) in Tongass Narrows and 1.76 mg/l (21% saturation) in Ward Cove.

3. Decrease in DO with depth below the depth of maximum value. At those stations sampled at 40 meters depth, DO ranged from 4.51 mg/l (47% saturation) in Tongass Narrows to 1.96 mg/l (20% saturation) in Ward Cove.

Dissolved oxygen concentration at the 10 meter depth (approximate depth of maximum DO) was fairly uniform throughout the study area, varying between about 5.6 and 7.1 mg/l. At any given depth much above or below the 10 meter depth, DO in Ward Cove was considerably less than in Tongass Narrows. This latter feature is illustrated on Figure 4-6 which shows surface DO values in Ward Cove generally 4-5 mg/l less than those in Tongass Narrows.

pH. Vertical distribution of pH (Figures 4-3 and 4-4 and tabulated data in the Appendix) essentially followed the same pattern as for dissolved oxygen concentration, i.e., maximum values generally between 5 and 10 meters depth with variable decrease toward the surface and toward the bottom from the depth of maximum value. Maximum pH for all stations ranged from about 7.9 to 8.1. Surface pH, shown on Figure 4-7, varied from low values of about 7.0 in Ward Cove to high values of about 8.0 in Tongass Narrows.

Secchi disc. Secchi-disc measurements, shown for all stations on Figure 4-8, varied from 0.3 to 1.2 meters in Ward Cove and from 2.6 to 4.6 meters in Tongass Narrows.

DISCUSSION

Water quality data collected during the 1951-52 pre-pollution studies are described in Report No. 7 primarily in terms of values representative of Ward Cove as a whole rather than as specific values for a particular time, location, and depth. In the discussion that follows, water quality observed on August 28, 1965 will be generally compared with those representative values in Report No. 7, and certain apparent effects of wastes on water quality will be described on the basis of the present survey.

WASTE DISTRIBUTION

Review of the surface SWL pattern (Figure 4-5) and the station curves (Figures 4-3 and 4-4) show two general areas of pulp mill waste influence: Ward Cove, represented by sampling Stations 6 and 8-13, where surface SWL ranges between 485 and 989 ppm; and Tongass Narrows, represented by sampling Stations 1-5 and 7, where surface SWL ranges between 24 and 41 ppm. The extremely high SWL concentrations throughout Ward Cove surface waters (485-989 ppm) are well above known toxicity threshholds for salmon fingerling, herring, candlefish, euphausids, copepods and mysids (6). Preliminary results of bioassays by this office in connection with pulp mill pollution in Puget Sound show that near-surface SWL concentrations in Ward Cove also considerably exceed values resulting in 100% mortality of egg and larvae stages of oysters and certain bottom fish, as well as in reduced oxygen production by phytoplankton. The Puget Sound studies also indicate that harmful effects to the marine environment occur at the lesser waste concentrations observed in Tongass Narrows (24-41 ppm). Physical conditions during the August 28 survey were not particularly contributory to detention of wastes in Ward Cove and, thus, such high SWL concentrations probably prevail in Ward Cove most of the time.

WATER QUALITY

Dissolved Oxygen. Examination of the surface DO pattern (Figure 3-6) and the station curves (Figures 4-3 and 4-4) indicates that the dissolved oxygen regime is separable into the same two areas as for SWL: Ward Cove (Stations 6 and 8-13), where surface DO ranges from 1.76-2.45 mg/l; and Tongass Narrows (Stations 1-5 and 7), where surface DO ranges from 6.41-7.24 mg/l. The DO regime is further divided into (a) near-surface waters above the depth of maximum DO (generally to about 10 meters depth) where DO decreases toward the surface as SWL increases, and (b) near-bottom waters beneath the depth of maximum DO where DO decreases with depth in the absence of strong SWL.

The envelope of DO versus depth in Ward Cove on August 28, formed by compositing the DO profiles measured at Stations 6 and 8-13, is shown on Figure 4-9. In addition, Figure 4-9 shows the DO profile at Station 4 in Tongass Narrows, a late-summer DO profile representative of Ward Cove prior to pollution (from Report No. 7), and the recommended minimum DO value of 5 mg/l. Review of this figure and the station curves (Figures 4-3 and 4-4) indicates:

1. Near-surface decrease in DO results from presence of pulp mill

wastes, the greater the SWL concentration--the less the DO.

2. Near-bottom decrease in DO in the absence of strong SWL, while expected as a natural characteristic, intensifies with nearness to the pulp mill, and is considerably more pronounced in Ward Cove than at more remote stations in Tongass Narrows. This feature results primarily from high oxygen demands of settleable solids in the pulp-mill waste discharge (about 1,100 tons per day, page 51) and consequent sludge beds within Ward Cove. During the August 28 survey, chunks of floating sludge material, buoyed from bottom deposits by gases of decomposition, were observed at the inner end of Ward Cove.

3. DO profile at Station 4, the station apparently least affected by pulp mill wastes (lowest SWL, highest DO) is from 1.2-2.5 mg/l less than the pre-pollution profile. Some portion of this difference may be attributable to natural processes, but the suppressing effect of SWL on near-surface DO at Station 4 is also noticeable.

4. The DO profile in Ward Cove on August 28, represented on Figure 4-9 by the composite envelope of all DO values measured within the Cove, is considerably degraded from that measured on that day at Station 4 in Tongass Narrows; the degradation ranges from 4.7-5.5 mg/l at the surface, 0.6-1.6 mg/l at 10 meters depth, and 1.0-2.5 mg/l at 40 meters depth. All of this degradation is attributed to waste discharge into Ward Cove, i.e., through the combined effects of effluent and sludge bed BOD and the inhibiting

effect of pulp mill waste on oxygen-producing phytoplankton.

5. DO throughout Ward Cove (envelope, Figure 4-9) is less than the recommended minimum value of 5 mg/l at depths less than 2-5 meters and greater than 15-19 meters. Preliminary results of bioassays conducted in Puget Sound by this office indicate that the presence of SWL and consequent lowered pH may compound the lethal effect of low DO on fingerling salmon.

In view of the season and evident oxygen resource beneath the SWL in Tongass Narrows (at about 10 meters depth), dissolved oxygen conditions observed on August 28, 1965 do not represent the most critical likely to occur during the year. The most critical period would probably be a month or two later, say October, when water temperatures are still fairly warm but photosynthetic production of dissolved oxygen is much reduced.

pH. The pattern of surface pH (Figure 4-7) also is divided into the same two areas as for SWL distribution: Ward Cove (Stations 6 and 8-13), where surface pH ranges from 6.94 to 7.12 in the presence of strong SWL (485-989 ppm); and Tongass Narrows (Stations 1-5 and 7), where surface pH ranges from 7.86 to 8.02 at lesser SWL concentrations (24-41 ppm). The relationship between surface pH and surface SWL, from low pH at high SWL to high pH at low SWL, is well-defined by the thirteen stations in Ward Cove and Tongass Narrows, and results from the combined effects of low pH effluent diluted into the surface waters and the relative excess of CO_2 from biochemical waste decomposition and reduced photosynthesis.

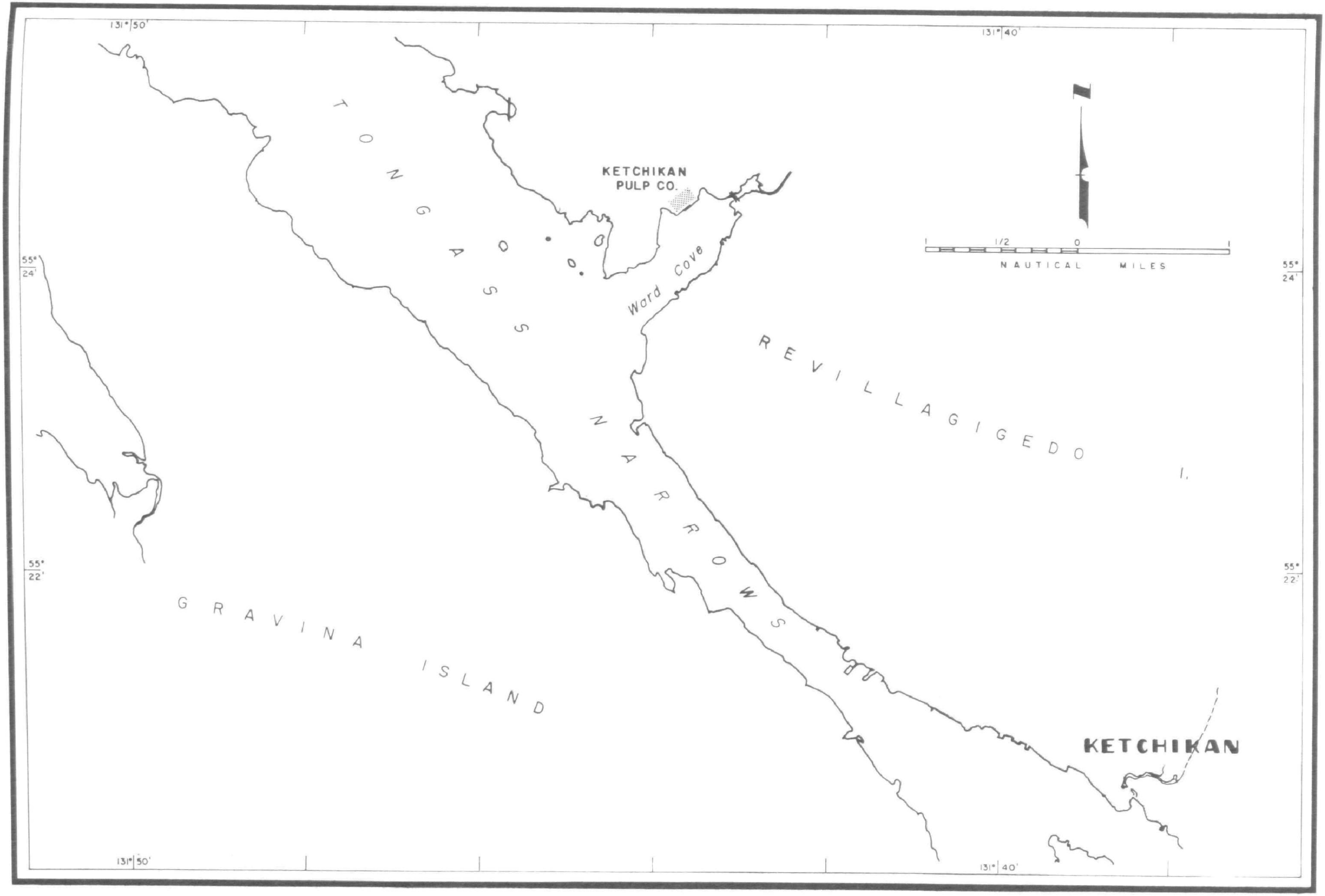

FIGURE 4-1. Location chart of the Ward Cove-Tongass Narrows area, near Ketchikan, Alaska.

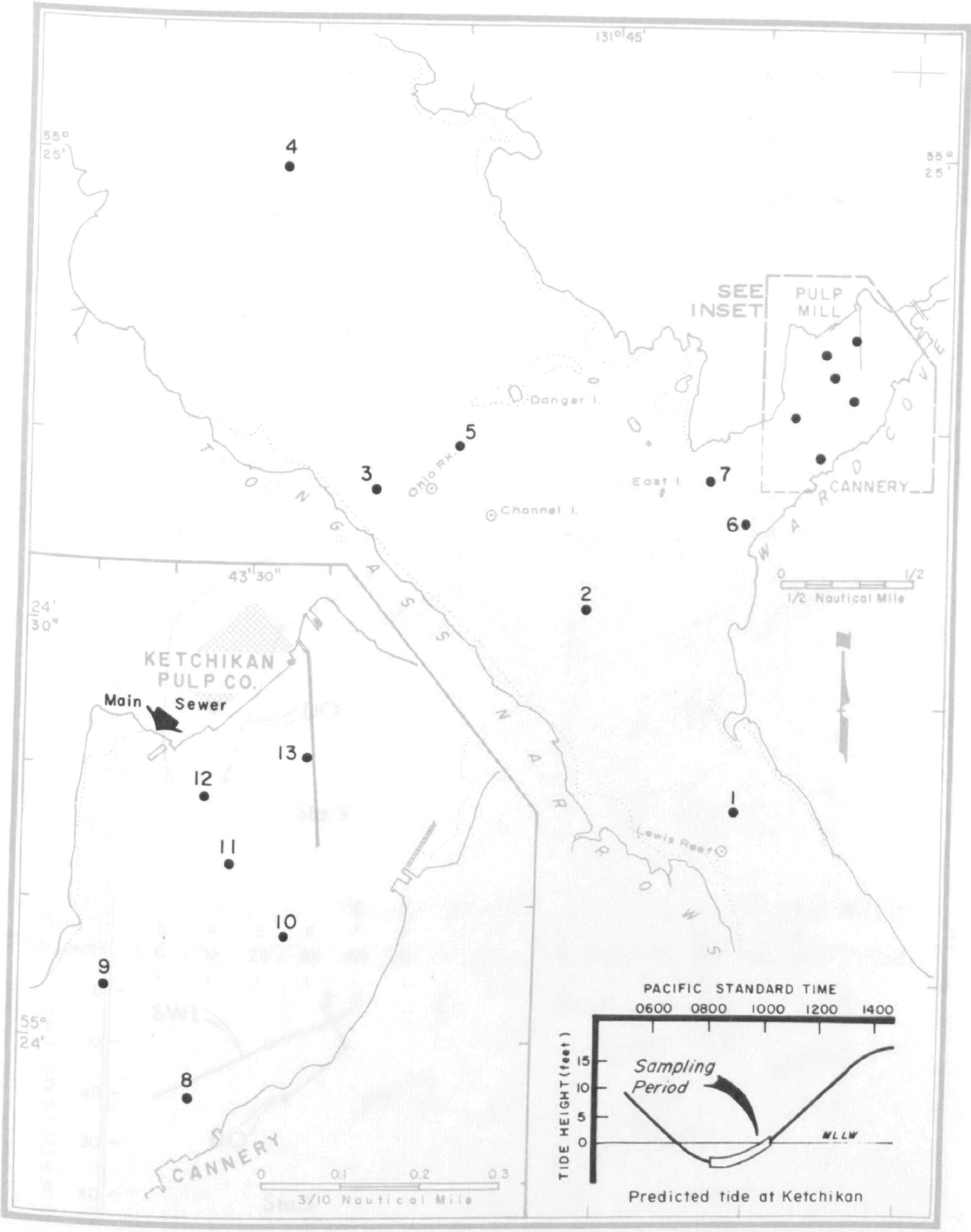

FIGURE 4-2. Ward Cove study area, sampling locations and sampling period; August 28, 1965.

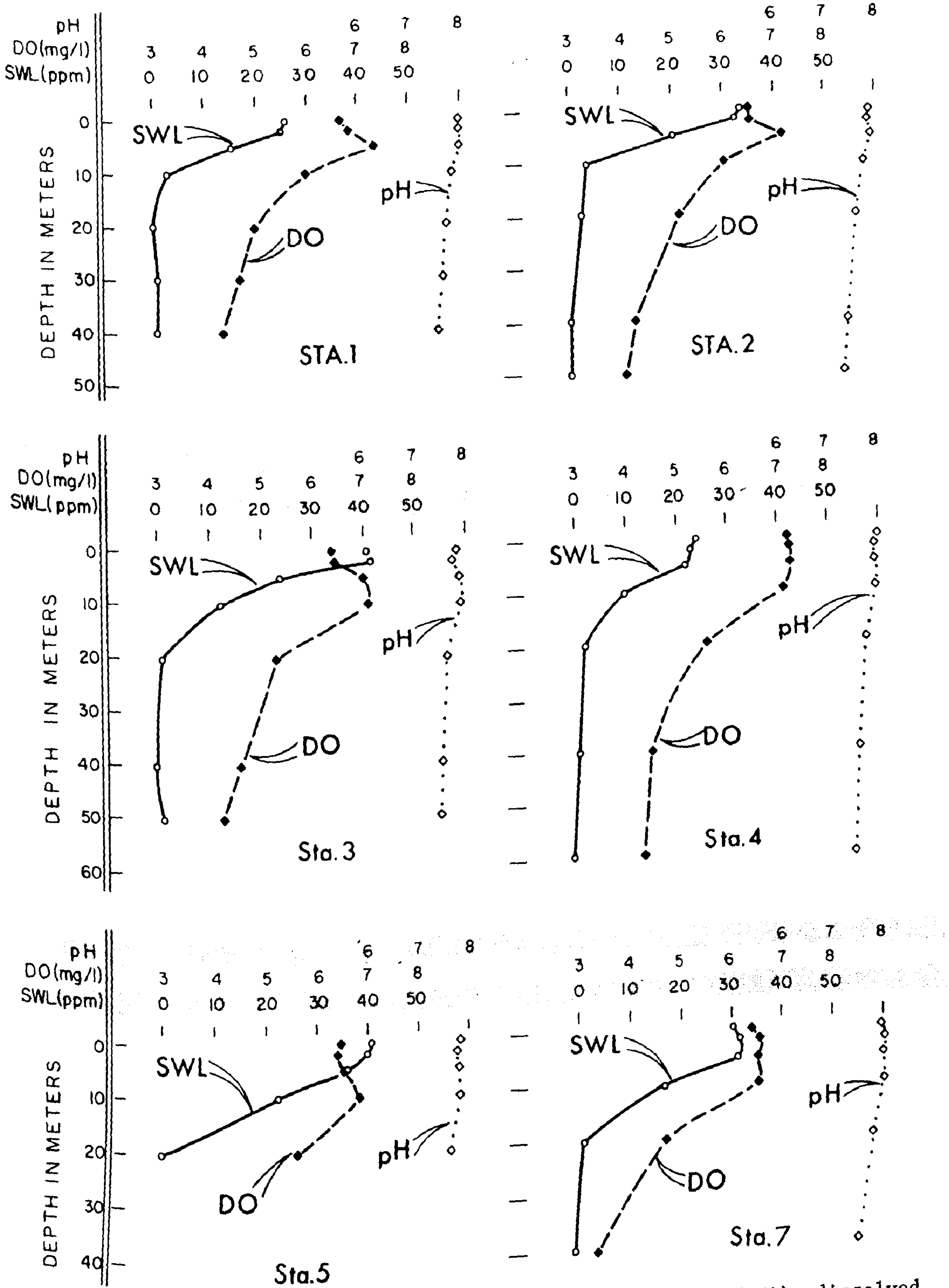

FIGURE 4-3. Vertical distributions of sulfite waste liquor (SWL), dissolved oxygen (D) and pH at Stations 1-5 and 7 in Ward Cove study area; August 28, 1965.

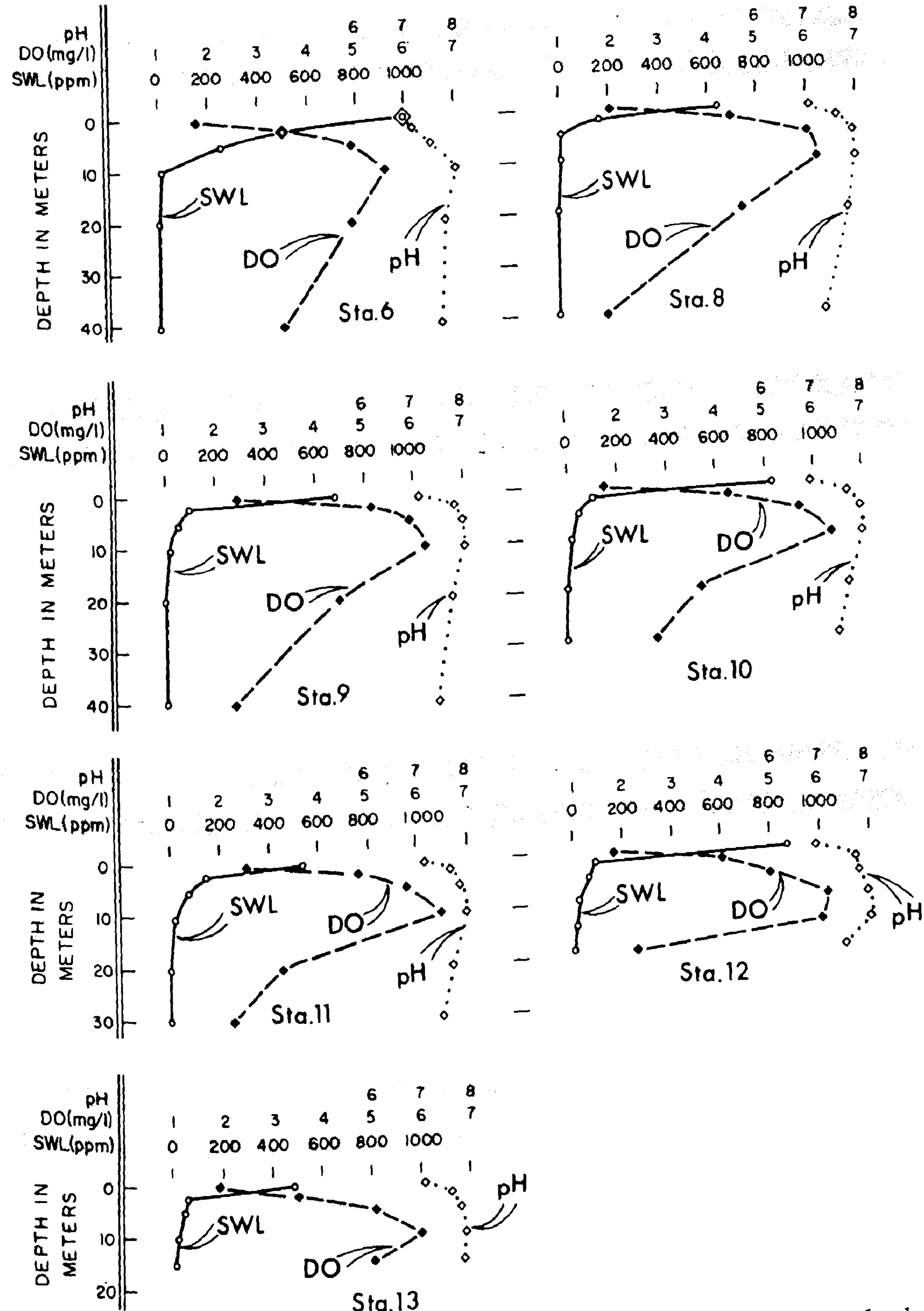

FIGURE 4-4. Vertical distributions of sulfite waste liquor (SWL), dissolved oxygen (DO) and pH at Stations 6 and 8-13 in Ward Cove study area; August 28, 1965.

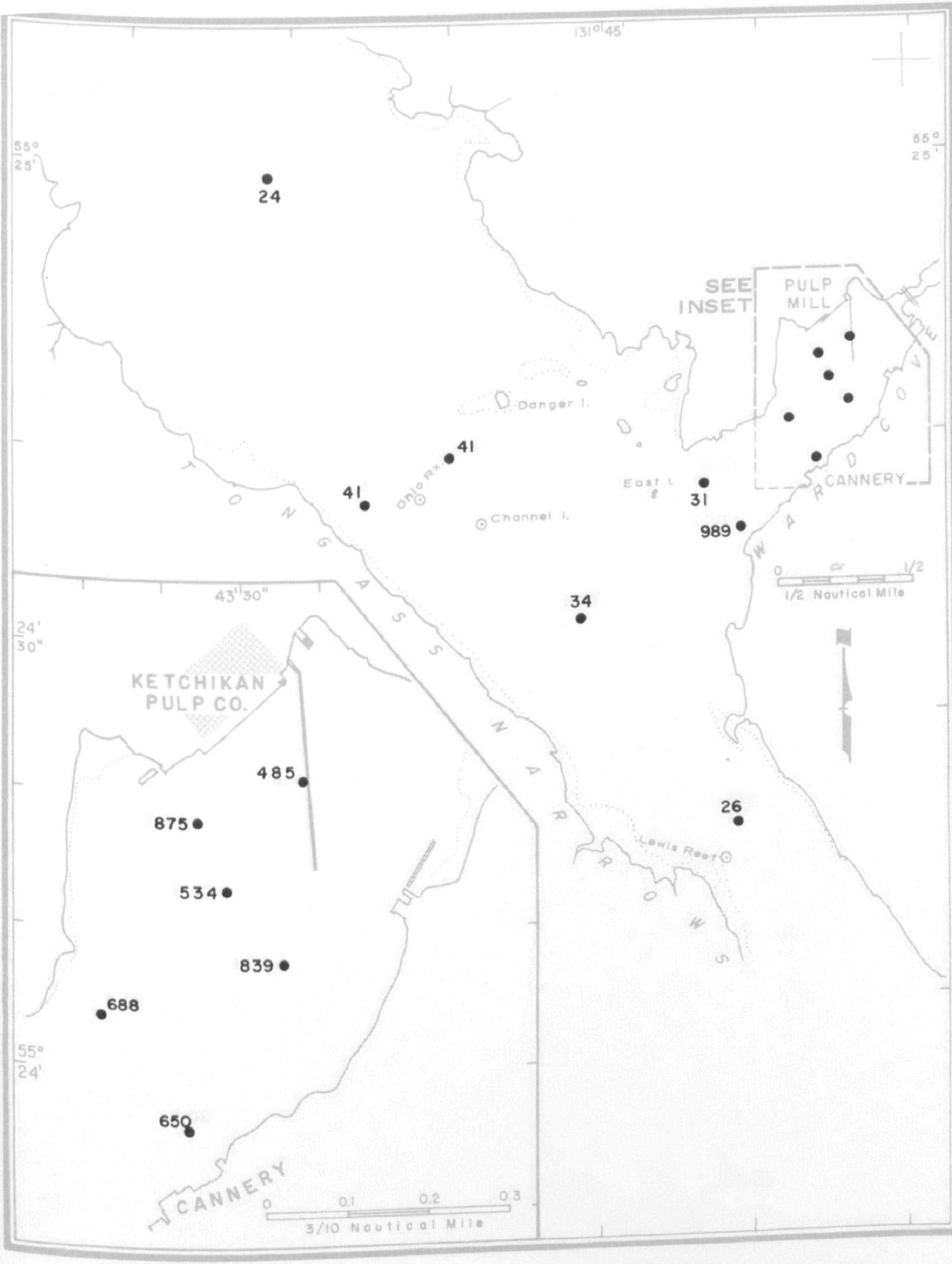

FIGURE 4-5. Surface concentrations (ppm) of sulfite waste liquor in Ward Cove study area; August 28, 1965.

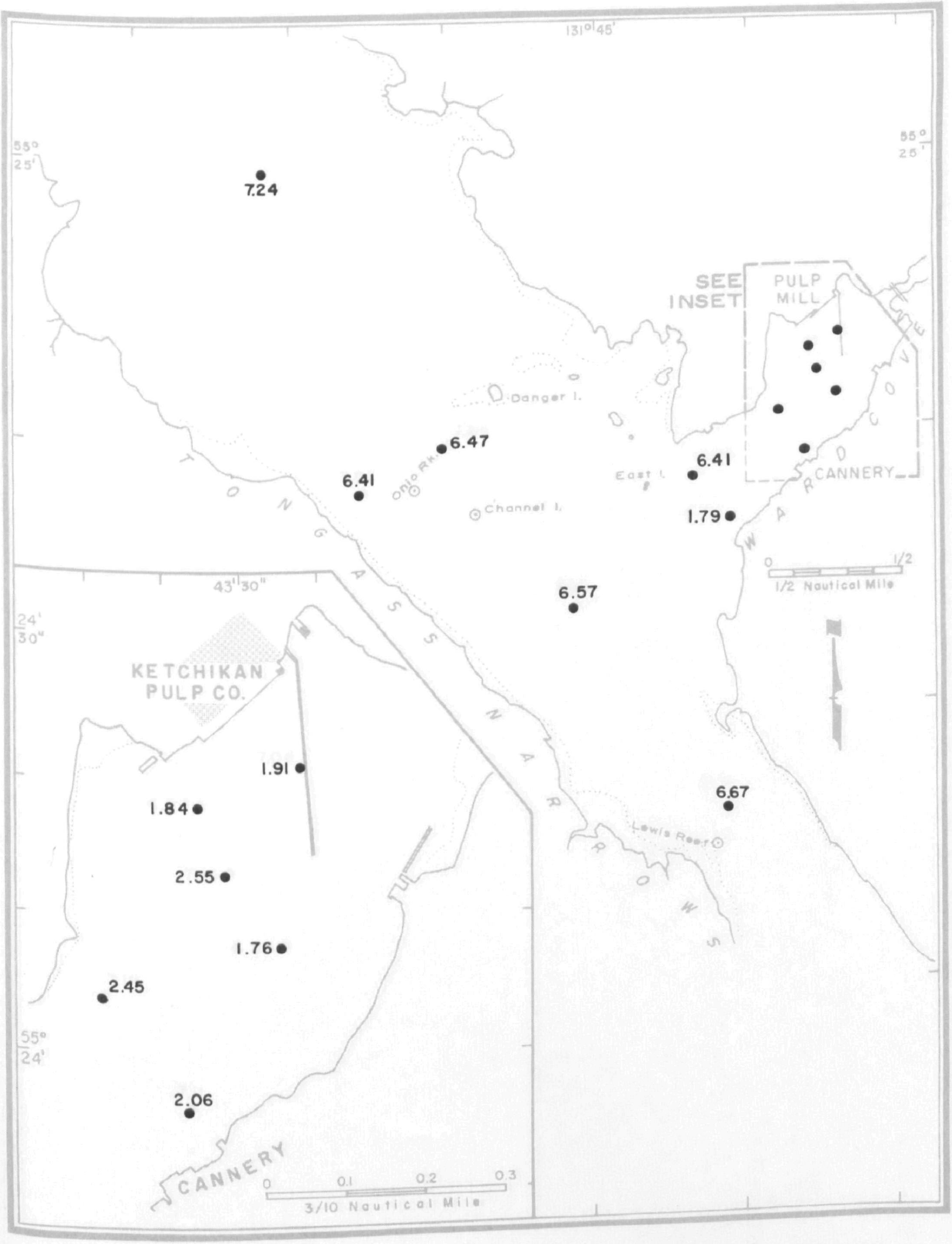

FIGURE 4-6. Surface concentrations (mg/l) of dissolved oxygen in Ward Cove study area; August 28, 1965.

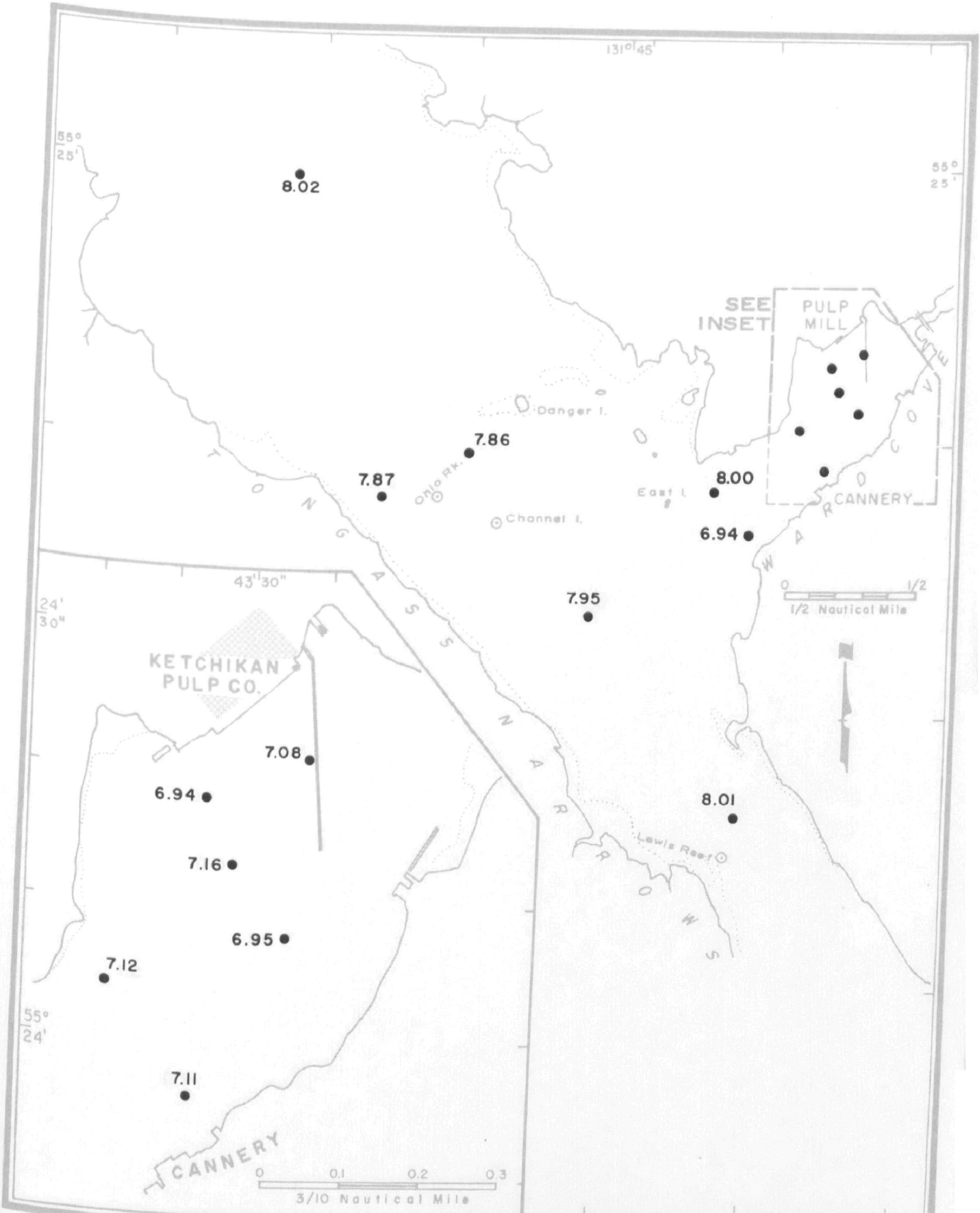

FIGURE 4-7. Surface pH in Ward Cove study area; August 28, 1965.

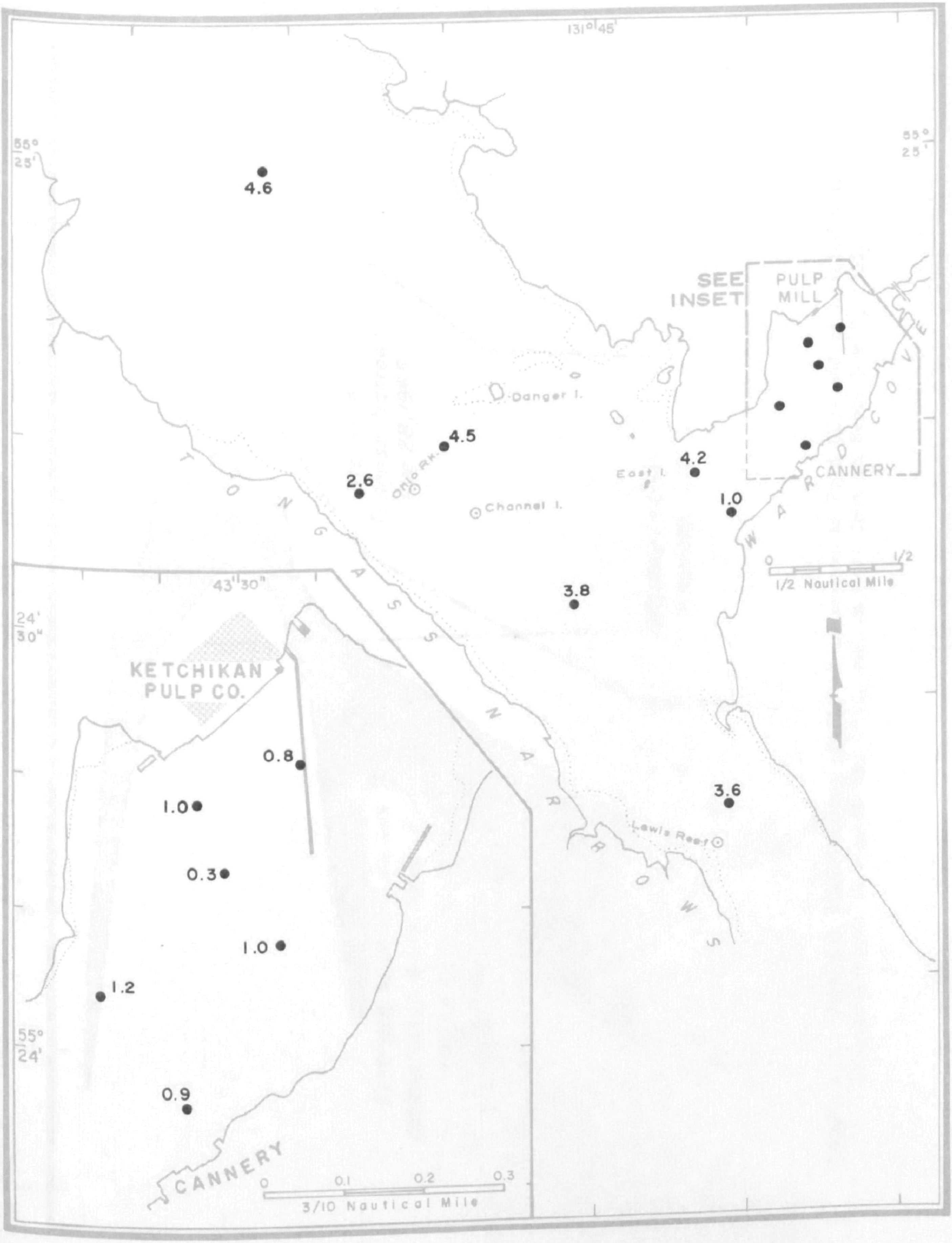

FIGURE 4-8. Secchi-disc measurements (meters) in Ward Cove study area; August 28, 1965.

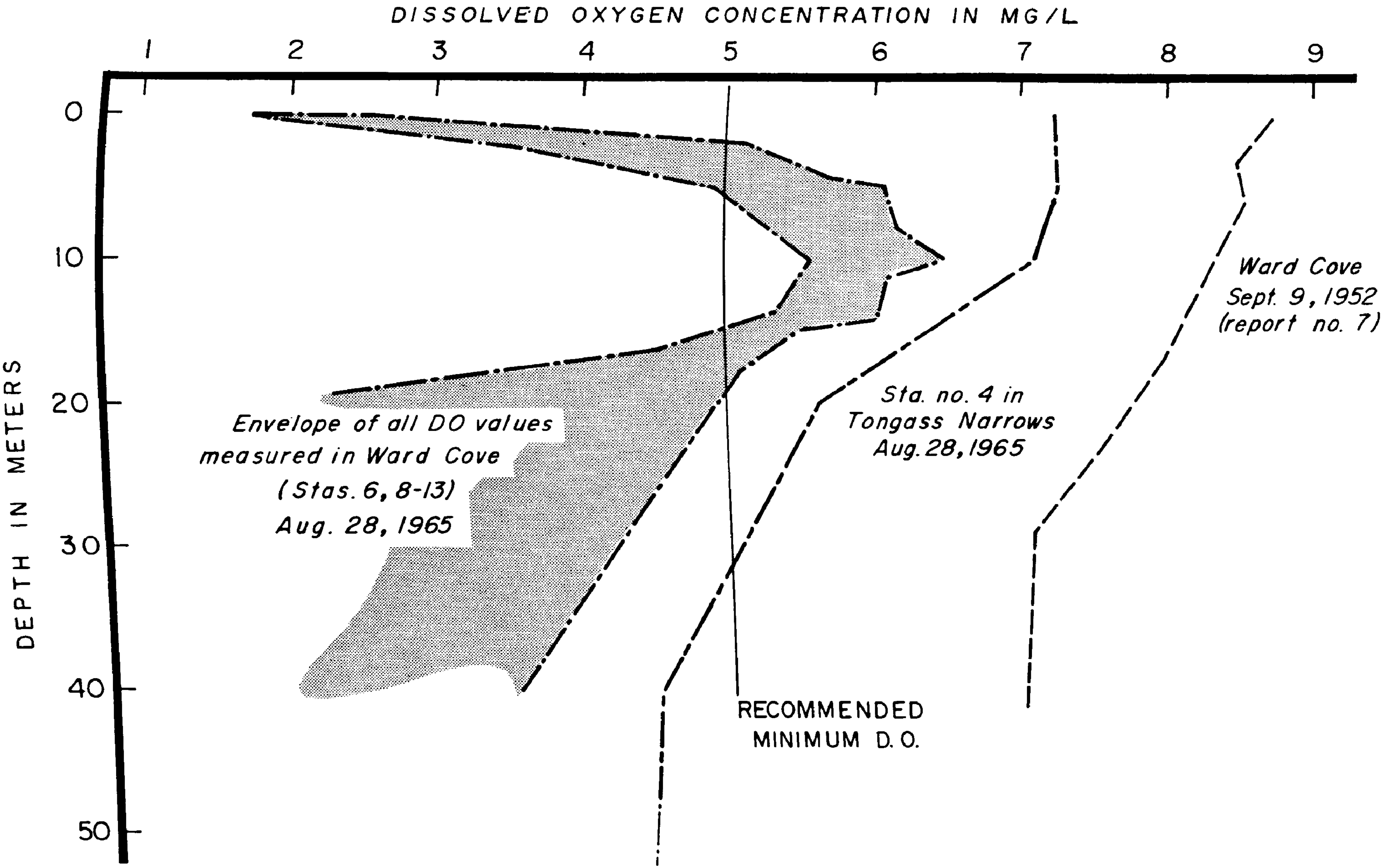

FIGURE 4-9. Vertical distribution of dissolved oxygen in Ward Cove and at Station 4 in Tongass-Narrows on August 28, 1965, and in Ward Cove on September 9, 1952.

LITERATURE CITED

AND

APPENDIX

LITERATURE CITED

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APPENDIX

All data collected during the Silver Bay and Ward Cove field studies are summarized herein. Data for each of the two survey areas are arranged by station and depth. A brief explanation of the data summary format follows:

CRUISE STATION DATE HOUR	) Self-explanatory
ZN	Time zone 8 denotes Pacific Standard Time.
LAT	North latitude of station location in degrees - minutes - seconds.
LONG	West longitude of station location in degrees - minutes - seconds.
WATER DEPTH	Total depth at station in meters.
WIND DIR	Wind direction in degrees referenced to true north.
SPD	Wind speed in knots.
AIR TEMP	Air temperature in degrees Fahrenheit.
SEC	Secchi-disc measurement in meters.

DEPTH	Sample depth in meters.
TEMP	*In situ* water temperature in degrees centigrade.
SALINITY	Sample salinity in parts per thousand.
SIGMA-T	A measure of water density; numerically, sigma-t = (Specific Gravity - 1) 1000.

OXYGEN	Dissolved oxygen concentration in terms of milligram-atoms per liter, milligrams per liter, and percent saturation.
pH	Measure of hydrogen-ion concentration.
SWL	Sulfite waste liquor concentration in parts per million as determined by the Pearl-Benson test (6).

CRUISE SILVER BAY 1 STATION 01

DATE 08/26/65 HR 1400 ZN 08 LAT 57-01-17 N LONG 135-18-10 W
WATER DEPTH 141 M WIND DIR 298 SPD 04 AIR TEMP. 60 SEC. 7.0 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	11.80	28.598	21.69	0.344	5.51	63	7.62	149
2	10.05	31.655	24.36	0.502	8.03	90	8.08	8
5	9.62	31.914	24.63	0.464	7.43	82	8.06	2
10	9.08	32.069	24.84	0.443	7.08	78	7.99	2
20	8.07	32.139	25.04	0.396	6.33	68	7.96	0
40	7.01	32.216	25.25	0.369	5.91	62	7.91	0
60	5.97	32.267	25.42	0.311	4.97	51	7.61	0
80	5.90	32.391	25.53	0.298	4.76	49	7.57	0

CRUISE SILVER BAY 1 STATION 02

DATE 08/26/65 HR 1431 ZN 08 LAT 57-01-55 N LONG 135-14-54 W
WATER DEPTH 73 M WIND DIR 298 SPD 03 AIR TEMP. 60 SEC. 2.8 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	12.68	27.268	20.51	0.316	5.05	58	7.65	441
2	10.36	31.284	24.02	0.435	6.96	78	7.92	139
5	9.70	31.779	24.51	0.484	7.74	86	7.99	12
10	8.72	31.995	24.83	0.472	7.55	82	8.05	3
20	7.95	32.034	24.98	0.448	7.16	77	7.86	0
40	6.51	32.123	25.24	0.362	5.79	60	7.68	0
60	5.70	32.222	25.42	0.244	3.91	40	7.54	0

CRUISE SILVER BAY 1 STATION 03

DATE 08/26/65 HR 1453 ZN 08 LAT 57-01-47 N LONG 135-14-42 W
WATER DEPTH 113 M WIND DIR 298 SPD 04 AIR TEMP. 60 SEC. 3.7 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	12.84	24.267	18.17	0.340	5.44	61	7.38	311
2	10.45	31.272	23.99	0.439	7.03	79	7.96	26
5	9.66	31.663	24.43	0.449	7.18	80	8.02	15
10	8.88	31.980	24.80	0.449	7.19	78	7.97	3
20	7.99	32.061	24.99	0.411	6.58	70	7.90	1
40	6.48	32.123	25.25	0.347	5.55	57	7.82	1
60	5.71	32.232	25.43	0.268	4.28	43	7.43	1
80	5.70	32.508	25.64	0.264	4.23	43	7.58	1

CRUISE SILVER BAY 1 STATION 04

DATE 08/26/65 HR 1509 ZN 08 LAT 57-01-39 N LONG 135-14-34 W
WATER DEPTH 37 M WIND DIR 298 SPD 04 AIR TEMP. 60 SEC. 5.2 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	12.99	23.361	17.44	0.374	5.98	68	7.61	239
2	10.64	27.026	20.67	0.450	7.20	79	8.01	128
5	9.15	31.786	24.60	0.438	7.01	77	8.03	7
10	8.79	31.991	24.82	0.432	6.91	75	8.00	1
20	7.81	32.077	25.03	0.404	6.47	69	7.86	0
40	6.55	32.143	25.25	0.338	5.41	56	7.72	0

CRUISE SILVER BAY 1 STATION 05

DATE 08/26/65 HR 1524 ZN 08 LAT 57-02-26 N LONG 135-13-52 W
WATER DEPTH 64 M WIND DIR 298 SPD 06 AIR TEMP. 60 SEC. 1.3 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	12.44	22.390	16.79	0.336	5.38	60	7.05	3220
2	9.94	31.485	24.24	0.470	7.52	84	8.02	137
5	9.13	31.717	24.55	0.436	6.97	76	7.96	43
10	8.57	31.980	24.84	0.405	6.48	70	7.83	4
20	7.55	32.034	25.03	0.368	5.88	62	7.67	2
40	6.43	32.127	25.26	0.320	5.12	53	7.56	1

CRUISE SILVER BAY 1 STATION 06

DATE 08/26/65 HR 1540 ZN 08 LAT 57-02-18 N LONG 135-13-40 W
WATER DEPTH 64 M WIND DIR 298 SPD 06 AIR TEMP. 60 SEC. 3.4 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	12.58	24.118	18.10	0.379	6.07	68	7.64	144
2	10.13	31.454	24.19	0.474	7.58	85	8.03	27
5	9.25	31.752	24.56	0.443	7.08	78	7.96	27
10	8.65	31.964	24.82	0.423	6.77	73	7.91	2
20	7.73	32.057	25.03	0.420	6.72	71	7.82	2
40	6.35	32.104	25.25	0.338	5.41	56	7.67	1

CRUISE SILVER BAY 1 STATION 07

DATE 08/26/65 HR 1552 ZN 08 LAT 57-02-08 N LONG 135-13-29 W
WATER DEPTH 73 M WIND DIR 298 SPD 10 AIR TEMP. 60 SEC. 6.2 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	13.73	20.650	15.23	0.321	5.14	58	7.41	213
2	10.47	31.296	24.01	0.444	7.10	80	8.02	22
5	9.10	31.833	24.65	0.451	7.22	79	7.96	3
10	8.61	31.968	24.83	0.419	6.70	73	7.90	2
20	7.86	32.065	25.01	0.406	6.50	69	7.84	1
40	6.46	32.127	25.25	0.334	5.34	55	7.70	0
60	5.80	32.240	25.42	0.245	3.92	40	7.44	1

CRUISE SILVER BAY 1 STATION 08

DATE 08/26/65 HR 1611 ZN 08 LAT 57-02-44 N LONG 135-13-32 W
WATER DEPTH 40 M WIND DIR 298 SPD 10 AIR TEMP. 60 SEC. 2.5 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	11.79	26.478	20.05	0.307	4.91	55	7.50	308
2	10.17	31.450	24.18	0.476	7.61	85	8.02	15
5	9.10	31.566	24.44	0.431	6.90	75	8.00	11
10	9.18	31.864	24.66	0.398	6.36	70	7.91	2
20	7.78	31.980	24.96	0.351	5.62	60	7.75	1
30	6.96	32.038	25.12	0.329	5.26	55	7.63	1

CRUISE SILVER BAY 1 STATION 09

DATE 08/26/65 HR 1626 ZN 08 LAT 57-02-35 N LONG 135-13-10 W
WATER DEPTH 63 M WIND DIR 298 SPD 04 AIR TEMP. 59 SEC. 2.8 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	10.18	15.150	11.54	0.441	7.05	71	7.50	281
2	10.47	31.392	24.08	0.484	7.74	87	7.97	16
5	9.42	31.597	24.41	0.461	7.38	81	7.98	12
10	8.67	31.906	24.77	0.426	6.81	74	7.99	2
20	7.73	32.007	24.99	0.393	6.28	67	7.94	1
40	6.41	32.081	25.22	0.319	5.11	52	7.86	1
50	5.90	32.147	25.34	0.294	4.71	48	7.56	2

CRUISE SILVER BAY 1 STATION 10

DATE 08/26/65 HR 1441 ZN 08 LAT 57-02-02 N LONG 135-11-53 W
WATER DEPTH 78 M WIND DIR 298 SPD 04 AIR TEMP. 59 SEC. 8.3 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	12.84	18.800	13.96	0.586	5.78	61	7.34	195
2	10.36	31.485	24.17	0.475	7.60	85	8.08	11
5	9.12	31.705	24.55	0.444	7.10	78	7.99	5
10	8.50	31.941	24.82	0.404	6.46	70	7.97	2
20	7.50	32.011	25.02	0.389	6.23	66	7.85	1
40	6.24	32.046	25.22	0.336	5.38	55	7.68	1
60	5.50	32.143	25.38	0.265	4.24	43	7.49	1

CRUISE SILVER BAY 1 STATION 11

DATE 08/26/65 HR 1659 ZN 08 LAT 57-01-55 N LONG 135-12-07 W
WATER DEPTH 82 M WIND DIR 298 SPD 02 AIR TEMP. 60 SEC. 7.0 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	13.96	18.950	13.88	0.319	5.10	57	7.22	71
2	10.19	31.616	24.30	0.482	7.71	87	8.04	6
5	9.39	31.729	24.52	0.450	7.20	79	8.03	3
10	8.58	31.895	24.78	0.418	6.68	72	7.90	2
20	7.52	32.018	25.03	0.384	6.15	65	7.79	2
40	6.33	32.069	25.22	0.324	5.19	53	7.57	1
60	5.90	32.182	25.36	0.256	4.09	42	7.38	1

CRUISE SILVER BAY 1 STATION 12

DATE 08/26/65 HR 1715 ZN 08 LAT 57-01-50 N LONG 135-12-17 W
WATER DEPTH 91 M WIND DIR 298 SPD 02 AIR TEMP. 60 SEC. 5.0 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	14.21	20.500	15.03	0.272	4.35	49	7.13	284
2	10.32	31.358	24.08	0.459	7.34	82	7.92	22
5	9.38	31.717	24.51	0.439	7.02	77	7.92	5
10	8.68	31.930	24.79	0.415	6.64	72	7.84	3
20	7.60	32.030	25.02	0.387	6.19	66	7.74	1
40	6.32	32.077	25.23	0.323	5.16	53	7.49	1
60	5.80	32.213	25.40	0.246	3.93	40	7.28	1
80	5.83	32.356	25.51	0.231	3.70	38	7.28	0

CRUISE SILVER BAY 1 STATION 13

DATE 08/26/65 HR 1742 ZN 08 LAT 57-00-37 N LONG 135-10-05 W
WATER DEPTH 64 M WIND DIR 298 SPD 05 AIR TEMP. 60 SEC. 5.5 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	14.35	21.300	15.61	0.285	4.56	52	7.08	268
2	10.03	31.253	24.05	0.473	7.56	84	7.88	24
5	9.12	31.535	24.41	0.463	7.40	81	7.87	13
10	8.11	31.852	24.81	0.442	7.07	76	7.61	2
20	7.14	31.895	24.98	0.395	6.32	66	7.50	2
40	5.93	31.953	25.18	0.382	6.11	62	7.38	2
60	--.--	31.984	--.--	0.361	5.77	--	7.33	3

CRUISE WARD COVE 1 STATION 1

DATE 08/28/65 HR 0811 ZN 8 LAT 55-22-38 N LONG 131-44-08 W
WATER DEPTH 43 M WIND DIR 345 SPD 07 AIR TEMP. 60 SEC. 3.6 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	MG/L	SATN.	PH	SWL
0	13.00	27.966	20.98	0.417	6.67	78	8.01	26
2	12.88	27.970	21.01	0.428	6.84	79	8.00	25
5	12.69	28.152	21.19	0.458	7.33	85	8.03	15
10	9.80	30.206	23.27	0.374	5.99	66	7.88	3
20	7.81	31.485	24.57	0.312	4.99	53	7.78	0
30	8.11	31.837	24.80	0.294	4.70	50	7.69	1
40	7.31	32.182	25.18	0.274	4.38	46	7.60	1

CRUISE WARD COVE 1 STATION 02

DATE 08/28/65 HR 0824 ZN 8 LAT 55-23-22 N LONG 131-45-09 W
WATER DEPTH 54 M WIND DIR 345 SPD 09 AIR TEMP. 60 SEC. 3.8 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	MG/L	SATN.	PH	SWL
0	13.30	27.920	20.89	0.411	6.57	77	7.95	34
2	13.04	27.920	20.94	0.413	6.60	77	7.90	33
5	12.88	28.034	21.06	0.451	7.21	84	7.97	21
10	10.59	29.879	22.89	0.381	6.10	68	7.85	4
20	8.22	31.296	24.36	0.327	5.23	56	7.70	3
40	6.70	32.236	25.31	0.273	4.37	45	7.56	1
50	6.49	32.473	25.52	0.261	4.17	43	7.48	1

CRUISE WARD COVE 1 STATION 03

DATE 08/28/65 HR 0846 ZN 8 LAT 55-23-48 N LONG 131-46-32 W
WATER DEPTH 60 M WIND DIR 345 SPD 09 AIR TEMP. 60 SEC. 2.6 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	MG/L	SATN.	PH	SWL
0	13.50	27.860	20.81	0.401	6.41	75	7.87	41
2	13.09	27.856	20.88	0.403	6.45	75	7.79	42
5	12.95	28.061	21.07	0.438	7.01	81	7.93	24
10	11.59	28.655	21.77	0.445	7.12	81	7.93	12
20	8.72	31.068	24.11	0.333	5.33	58	7.67	1
40	7.12	31.945	25.02	0.288	4.61	48	7.58	0
50	6.94	32.100	25.17	0.268	4.28	45	7.51	1

CRUISE WARD COVE 1 STATION 04

DATE 08/28/65 HR 0905 ZN 8 LAT 55-24-57 N LONG 131-47-10 W
WATER DEPTH 64 M WIND DIR 345 SPD 01 AIR TEMP. 60 SEC. 4.6 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	13.60	28.130	21.00	0.453	7.24	85	8.02	24
2	13.33	28.126	21.05	0.453	7.25	85	7.95	23
5	13.16	28.168	21.11	0.454	7.27	85	7.95	22
10	12.39	28.514	21.52	0.446	7.14	82	7.96	10
20	9.30	30.683	23.72	0.352	5.63	61	7.79	2
40	6.91	32.069	25.15	0.282	4.51	47	7.64	1
60	6.55	32.411	25.46	0.273	4.37	45	7.54	0

CRUISE WARD COVE 1 STATION 05

DATE 08/28/65 HR 0920 ZN 8 LAT 55-23-57 N LONG 131-46-00 W
WATER DEPTH 29 M WIND DIR 298 SPD 09 AIR TEMP. 60 SEC. 4.5 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	13.50	27.958	20.88	0.404	6.47	76	7.86	41
2	13.09	27.962	20.96	0.401	6.42	75	7.80	40
5	13.07	28.008	21.00	0.407	6.51	76	7.84	36
10	12.34	28.335	21.39	0.428	6.85	79	7.87	22
20	9.20	30.667	23.72	0.352	5.63	61	7.69	0

CRUISE WARD COVE 1 STATION 06

DATE 08/28/65 HR 0935 ZN 8 LAT 55-23-41 N LONG 131-44-06 W
WATER DEPTH 47 M WIND DIR 298 SPD 09 AIR TEMP. 60 SEC. 1.0 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	13.46	25.706	19.16	0.112	1.79	21	6.94	989
2	13.23	26.916	20.13	0.220	3.52	41	7.15	507
5	12.90	27.598	20.72	0.308	4.92	57	7.52	254
10	12.01	28.629	21.68	0.349	5.59	64	8.08	16
20	8.42	31.079	24.16	0.308	4.92	53	7.83	1
40	6.85	32.123	25.20	0.219	3.51	37	7.72	1

CRUISE WARD COVE 1 STATION 07

DATE 08/28/65 HR 0952 ZN 8 LAT 55-23-50 N LONG 131-44-20 W
WATER DEPTH 49 M WIND DIR SPD 00 AIR TEMP. 60 SEC. 4.2 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	13.41	28.008	20.94	0.401	6.41	75	8.00	31
2	13.16	28.015	20.99	0.409	6.55	76	8.07	32
5	13.08	28.015	21.01	0.409	6.55	76	8.04	32
10	12.32	28.442	21.48	0.409	6.55	75	8.03	17
20	8.46	31.106	24.18	0.296	4.73	51	7.85	1
40	6.83	32.147	25.22	0.215	3.44	36	7.62	0

CRUISE WARD COVE 1 STATION 08

DATE 08/28/65 HR 1005 ZN 8 LAT 55-23-56 N LONG 131-43-37 W
WATER DEPTH 42 M WIND DIR SPD 00 AIR TEMP. 60 SEC. 0.9 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	14.21	26.067	19.29	0.129	2.06	24	7.11	650
2	13.37	27.496	20.55	0.283	4.52	53	7.68	166
5	12.99	28.617	21.49	0.380	6.08	71	7.97	17
10	12.02	28.617	21.67	0.391	6.26	72	8.03	17
20	8.75	30.971	24.03	0.295	4.72	51	7.88	1
40	6.87	32.011	25.11	0.123	1.96	20	7.40	2

CRUISE WARD COVE 1 STATION 09

DATE 08/28/65 HR 1018 ZN 8 LAT 55-24-03 N LONG 131-43-48 W
WATER DEPTH 44 M WIND DIR 254 SPD 04 AIR TEMP. 66 SEC. 1.2 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	14.13	26.203	19.41	0.153	2.45	29	7.12	688
2	13.30	27.738	20.75	0.322	5.15	60	7.84	96
5	13.08	27.927	20.94	0.371	5.94	69	7.98	53
10	12.46	28.438	21.45	0.390	6.24	72	8.05	21
20	8.80	30.933	23.99	0.283	4.52	49	7.80	3
40	6.89	32.088	25.17	0.149	2.39	25	7.51	2

CRUISE WARD COVE 1 STATION 10

DATE 08/28/65 HR 1031 ZN 8 LAT 55-24-08 N LONG 131-43-25 W
WATER DEPTH 34 M WIND DIR 254 SPD 04 AIR TEMP. 66 SEC. 1.0 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	14.56	24.464	18.00	0.110	1.76	21	6.95	839
2	13.34	27.556	20.61	0.271	4.33	51	7.75	104
5	12.98	27.905	20.94	0.360	5.76	67	8.00	51
10	12.21	28.206	21.31	0.403	6.45	74	8.04	22
20	9.31	30.579	23.64	0.241	3.85	42	7.78	3
30	7.77	31.485	24.57	0.178	2.85	30	7.55	2

CRUISE WARD COVE 1 STATION 11

DATE 08/28/65 HR 1043 ZN 8 LAT 55-24-13 N LONG 131-43-32 W
WATER DEPTH 31 M WIND DIR SPD 00 AIR TEMP. 65 SEC. 0.3 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	14.28	23.831	17.57	0.159	2.55	30	7.16	534
2	13.26	27.386	20.49	0.301	4.81	56	7.68	146
5	12.99	27.818	20.87	0.362	5.79	67	7.88	78
10	12.73	28.194	21.21	0.406	6.50	75	8.03	24
20	9.16	30.614	23.69	0.206	3.29	36	7.72	4
30	7.79	31.504	24.58	0.141	2.26	24	7.53	2

CRUISE WARD COVE 1 STATION 12

DATE 08/28/65 HR 1058 ZN 8 LAT 55-24-18 N LONG 131-43-36 W
WATER DEPTH 21 M WIND DIR SPD 00 AIR TEMP. 65 SEC. 1.0 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	14.63	24.095	17.70	0.115	1.84	22	6.94	874
2	13.22	27.659	20.71	0.254	4.06	47	7.72	91
4	13.06	27.814	20.86	0.314	5.02	58	7.80	66
14	12.28	28.564	21.58	0.378	6.05	69	8.04	17
9	12.81	28.133	21.15	0.387	6.19	72	7.98	26
19	9.02	30.756	23.82	0.145	2.32	25	7.51	3

CRUISE WARD COVE 1 STATION 13

DATE 08/28/65 HR 1112 ZN 8 LAT 55-24-22 N LONG 131-43-22 W
WATER DEPTH 16 M WIND DIR SPD 00 AIR TEMP. 65 SEC. 0.8 M

DEPTH	TEMP.	SALINITY	SIGMA-T	OXYGEN MG-AT.	OXYGEN MG/L	OXYGEN SATN.	PH	SWL
0	14.45	22.516	16.53	0.119	1.91	22	7.08	485
2	13.53	27.371	20.43	0.222	3.55	42	7.60	63
5	13.00	27.213	20.41	0.318	5.10	59	7.81	49
10	12.63	28.259	21.28	0.377	6.03	70	7.90	24
15	11.89	28.598	21.67	0.316	5.05	58	7.87	18